EFFECT OF NUTRIENT VARIABILITY ON FEED EFFICIENCY

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Introduction

The importance of feed costs to beef production has been well documented and many studies have calculated that over 60% of production costs are attributable to feed purchase. The increased cost of grain and feed ingredients has created an environment where feed costs impact beef profitability perhaps more so than any point in history. The first response to increased production costs in any business is increased efficiency of production. I believe the two questions that we should ask are what is the maximum efficiency possible by beef cattle and how can diets be formulated to allow the animal to achieve maximum efficiency. In the text below I attempt to address these two questions.

When considering the maximum efficiency possible by beef cattle, there are two points that need to be known. First, we need to determine the maximum efficiency that can be biologically achieved by the animal. Second, we need to determine the range in maximum efficiency that exists in the population. Feed efficiency should be addressed just as we have addressed growth, carcass and other economic traits. We should manage and/or feed cattle to maximize expression of the traits of interest (growth rate, marbling score, feed efficiency, etc) and then select for superior genetics in these traits.

The greatest loss of energy in any diet is fecal energy, thus the need to improve diet digestibility by the animal. The second greatest practical inefficiency, in my opinion, comes from diets that deliver an imbalance of nutrients for absorption and metabolism by the animal. In production systems, this is typically caused by an imbalance of amino acids, or protein, and energy. We do not formulate diets that allow beef cattle to maximize their potential for feed efficiency.

Biological Limits of Feed Efficiency

The majority of closeouts for feedlot cattle will calculate feed to gain ratios ranging from 5 to 8. This is an average over the feeding period, and will be influenced by genetic ability of the cattle, diet ingredients, environmental conditions, and other factors. Given all the factors that are known to influence feed efficiency, the goal for cattle to finish with a feed to gain ratio of less than 5 is still elusive. The efficiency of a calf changes two-fold or more during the feedlot phase of production. A weaned calf that is laying down predominantly muscle tissue will have a feed to gain of 4 or less. When that calf is near finishing its feed to gain ratio can be greater than 10. Growth rate can influence feed efficiency, with faster growing calves being more efficient. However, as shown in Figure 1 the range in feed efficiency varies regardless of growth rate. Figure 1 shows the average daily gain of 41 calves (x axis) and their feed efficiency (y axis). As the rate of gain increases along the x axis, the graph tends to slope downward or as the average daily gain increases the feed efficiency average improves. This is expected. What is important to point out is that there is considerable range in feed efficiency among animals regardless of growth rate. In these calves the feed efficiency ranged from 7.8 to 4.4. Figure 2 shows data from these same calves but feed to gain ratio is calculated during the growing phase (up to approximately 850 lbs). The range in feed to gain of these calves is 4.8 to 1.5 and the average is less than the value for the entire feeding period shown in Figure 1. I believe there are two factors to view as important from these data. First is the change in feed efficiency that occurs as the animal increases in body weight. It is likely that we can not continue to feed cattle to the same historical endpoint if efficiency of feed use is not improved. Second is the genetic potential for improving feed efficiency. Several of the calves in this group of 41 had feed to gains of 2.5 or less during the growth phase and 5 or less through the feeding period. Emmans (1994) reported that the only difference between cattle and swine in growth efficiency when corrected for composition of tissue gain was the energy lost as methane. In corn-based diets the energy lost from methane generation approximates 0.5 lbs of feed per lb of gain. The feed to gain ratios of the efficient calves in this group are in agreement with Emmans research. The genetic potential for improving feed efficiency is great. The possibility now exists to identify genetics that improve efficiency via incorporating residual feed intake measurement into bull and heifer tests. However, it is my view that the diets we feed to cattle must allow them to achieve their maximum potential for efficient production, or it will be impossible to exploit the full potential of beef cattle efficiency.

Balancing Diets to Maximize Feed Efficiency

Roughage removal from the diet.

Roughage is placed into concentrate-based diets for the purpose of maintaining rumen health. Diets fed to feedlot cattle typically contain 2 to 10% roughage. While the cost of roughage per unit of weight is relatively cheap, its cost per unit of digestible energy can be one of the more expensive feedstuffs. We have measured the digestibility of roughage in grain-based diets to be 15% or less. Roughage will substantially reduce the digestible energy content of the diet, and therefore reduce feed efficiency. Since roughage is placed in the diet primarily to prevent acidosis, we asked the question could roughage be removed if acidosis was prevented by another means. Fermentation in the rumen is influenced by degradable protein; as degradable protein increases the rate of fermentation and acid production increases (Van Kessel and Russell, 1996). Therefore the need for roughage to prevent acidosis in the rumen could be alleviated if degradable protein was limited. On the other hand microbial efficiency, and therefore microbial protein synthesis, can be reduced if rumen degradable protein or nitrogen is limiting. The most important and inexpensive source of amino acids for the animal is derived from microbial protein produced in the rumen. The optimum target for degradable protein and nitrogen is the level that will allow microbial efficiency to be maximized yet prevent rapid production of acids from fermentation.

Meng et al (1999) reported efficiency equations for nonstructural carbohydrate, structural carbohydrate, and protein-fermenting ruminal microflora groups. Russell et al (1983) reported that nonstructural-carbohydrate fermenting bacteria require two-thirds of the nitrogen used for growth from rumen degradable protein, with the remaining nitrogen required and all the nitrogen required by structural carbohydrate-fermenting bacteria coming from rumen degradable nitrogen. We used the microbial efficiency equations and form of nitrogen preferences to calculate the predicted rumen degradable protein needed in the diet. When diets were blended to contain typical protein content (14% crude protein) and compared to a diet with the degradable protein balanced for microbial requirement ruminal pH was increased. Table 1 shows the pH of rumen fluid taken from three ruminally-fistulated steers (A, B and C). Reducing the degradable protein in the diet increased ruminal pH from 5.2 to 5.6. Table 2 presents data from an experiment where diets with increasing levels of degradable protein were fed and microbial efficiency measured in steers. Microbial protein was maximzed when the degradable protein was greater than the predicted requirement for degradable protein. Furthermore degradable protein, or true protein, and not rumen degradable nitrogen (biuret) was required to maximize microbial efficiency. The percentage degradable protein required to maximize microbial efficiency was approximately 4%, which is less than is typically fed in diets to growing cattle. We have been feeding diets to research cattle in the feedlot for five years now without any roughage in the diet. Our experience with these cattle keeps leading us to the conclusion that balancing diets for optimum degradable protein content is effective in preventing acidosis and allowing roughage removal from the diet.

Optimizing Amino Acid Flow to the Small Intestine

Development of the microbial efficiency equations allows the estimation of microbial amino acid flow to the small intestine. These data were then placed into the CNCPS (Russell et al, 1992) model to predict total amino acid flow (diet and microbe) to the intestine. The only other change we made to the CNCPS model was restoring the arginine requirement for growth to the level originally reported in version 1. We balance dietary ingredients for a set level of growth by using Emmans equations to determine the energy (effective energy which can be calculated from metabolizable energy values) required for growth, microbial efficiency and ruminal protein degradability equations to achieve the required level of absorbable amino acids for growth, and microbial efficiency equations to determine the level of rumen degradable protein needed in the diet. Table 3 shows the results from one experiment where the effect of this diet balancing approach was evaluated in steers and heifers. The diets fed to calves were a control diet designed to mimic a typical feedlot diet (SBM) and consisted of corn, soybean meal and 10% hay (14% crude protein). The test diet is designated as BM and used bloodmeal as the primary protein source. The test diet also had hay added at 10% to determine the effect roughage had on animal performance (BM Hay). The last two diets were SBM-H Pair fed which was the SBM diet fed at the same level of intake as the BM diet and Urea which had supplemental protein added to the diet in the form of urea to compare a nonprotein nitrogen diet to protein-nitrogen diets. The BM diet resulted in better feed efficiencies than the other diets. A large part of the improvement can be attributed to hay removal, however the totality of improvement was greater than what can be stoichometrically attributed to hay alone. Both genders showed feed efficiency improvements of approximately 1 lb of feed per lb of gain.

A second experiment is reported in Tables 4 through 8. Table 4 lists the ingredient composition of three diets fed to cattle in this experiment. Two diets were fed (phase one and two) based upon the predicted absorbable amino acid requirements of calves during the growing and finishing phase. A control diet was fed (SBM) and compared to two diets balanced for degradable protein and absorbable amino acid flow to the intestine. Two rumen-stable protein sources were used (bloodmeal and fishmeal) to test if balancing for the limiting amino acid would yield similar performance results. There were no differences in feed efficiency between the two amino acid balanced diets, and both diets promoted better feed efficiencies than the control diet (Table 5). The improvement in feed efficiency was approximately 0.6 lbs of feed per lb of gain. Another difference that occurs between conventional and no roughage diets is the volume of manure output. In the growing phase (P1) and finishing phase (P2) wet manure volume was reduced 60 and 40 %, respectively, when no roughage diets were fed (Table 6).

The thesis of our approach to formulating diets is that we meet the animal's limiting amino acid requirement. The first limiting amino acid will vary depending upon dietary proteins, but across a wide range of diets the equations we have used identified arginine, lysine, methionine, histidine and threonine as limiting. In the soybean meal, fishmeal and bloodmeal diets of this experiment arginine was calculated as the most limiting. The diets were balanced to support 5 lbs of daily gain during the growing phase and 3.5 lbs of gain during the finishing phase. Based upon these predictions and the growth measured in the calves, the ratio of arginine predicted to have been supplied to the animal's arginine requirement was near 1 for each diet (Table 7). The research we have done to date has been predominantly with corn-based diets. On these diets, arginine is consistently the first-limiting amino acid. The collective inference from the experiments we have conducted is that maximum daily gain will be achieved when 85% of the arginine requirement is met, but feed efficiency is not maximized until the arginine requirement is met in full.

The results we have measured in performance by formulating diets to allow for roughage removal and meet absorbable amino acid requirement was supported by the findings of Emmans regarding energy expenditure for maintenance and growth functions. The data in beef also was aligned in nutritional concept with data in poultry and swine species. A discrepancy occurred however in that net energy (NE) calculations led to the interpretation that feed efficiencies being measured were not possible. As shown in Table 8, the ratio of NE required for growth to the NE consumed by the animal was less than 0.8 for the balanced diets but 1.0

for the conventional diet. However, when Emmans' effective energy (EE) equations were used to compute the same ratio, the EE required for growth to the EE consumed was 1.0 for both balanced diets. The EE ratio for the conventional diet was 1.13, with the elevated ratio most likely influenced by the mathematical assumption in NE value of the diet that the hay was extensively digested. There is substantial research available to support the conclusion that diets can be balanced to improve feed efficiency of beef cattle.

Potential to Improve Feed Efficiency in No-Corn Diets

The potential to improve feed efficiency in cattle fed diets with no or limited corn is also possible via varying dietary ingredients to meet nutrient requirements. Bulls were fed 6 lbs of a typical supplement of distillers grains and corn or 6 lbs of supplement that balanced absorbable amino supply to that required for a targeted gain of 3 lbs. The bulls were placed on study after weaning, fed to approximately 900 lbs, and offered grass hay free-choice and grazed on stock-piled tall fescue pasture. The bulls fed the control supplement gained 2.1 lbs per day and the steers fed the balanced supplement gained 2.7 lbs per day. In another study steers were fed a diet based upon soyhulls, wheat midds, and corn with distillers grains added at increasing percentages (Table 9). The optimum level of distillers grains was predicted to be the 28% level because this level balanced the absorbable amino acid to energy density ratio for this diet. This level of distillers grains did result in the best growth performance, with average daily gain being increased by 0.4 lbs per day and feed efficiency being improved by 0.3 lbs of feed per lb of gain. Our research has led us to conclude that varying ingredients in the diet to improve feed efficiency has merit for diets that are concentrate or forage based.

How Technically Complicated can Diet Formulation Become?

Genetic selection is now possible that can improve efficiency by 20% or more. Technology exists that measures weight gain and body weight real-time in the feedlot. Rumen-stable amino acid products are expanding that will allow greater precision in matching amino acid supply in the diet with growth requirements. Additives are in play that will influence the composition of gain and the efficiency that tissue gain is accrued. Each of these advances is affected and can be enhanced by nutrient content of the diet. The interplay of economic benefit, ability to adopt more complex diet formulations in a production system, and identification and sorting of animals with varying genetic ability will ultimately determine how complicated diet formulation will become. This is particularly true when all the diet changes required to optimize available technology is considered. The possibility exists now to construct diets that improve feed efficiency by formulating diets for RDP and amino acid requirements. We have also measured economic benefit in phase feeding cattle based upon changes in lean tissue growth. I believe there is no question that feed costs and economic pressures will require us to formulate diets to improve feed efficiency as a primary production factor if not the primary production factor in the future. I also believe that we are further in our knowledge base of producing cattle that are efficient and formulating diets that maximize feed efficiency than we currently practice. The need now is to move what has been done in research to production.

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Figure 1. Graph of Feed Efficiency Plotted against Average Daily Gain

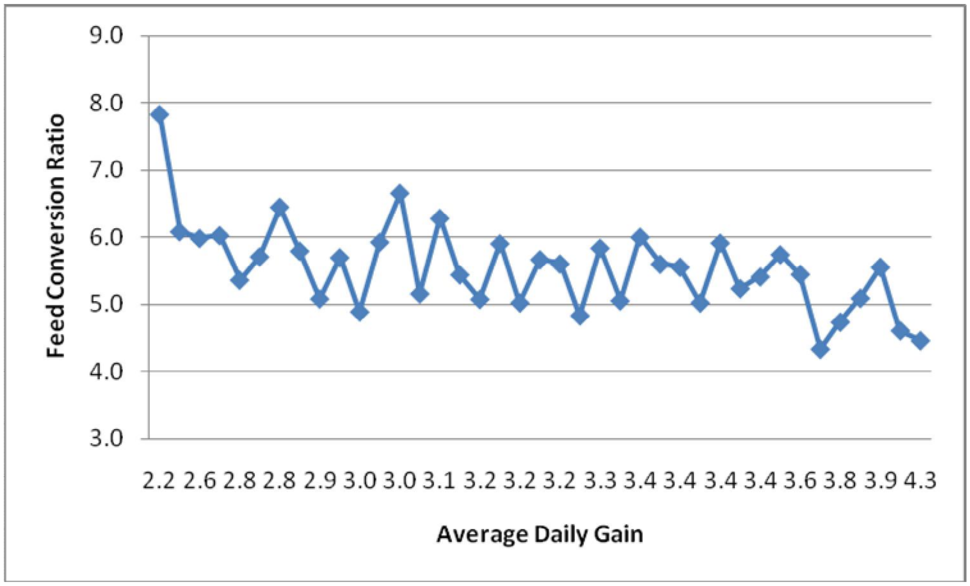

Figure 2. Feed Conversion Ratio of 41 Calves

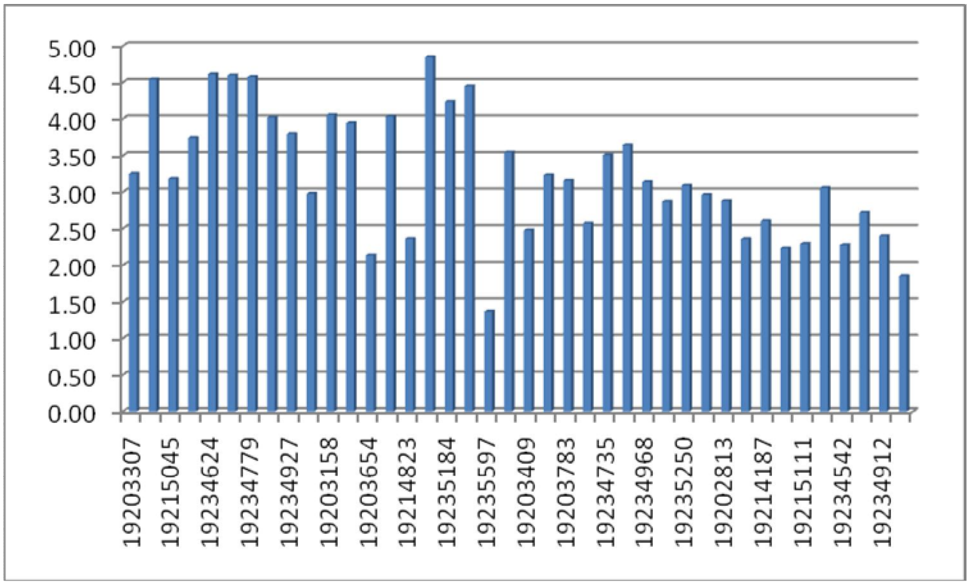

Table 1. Effect of Balanced RDP on Ruminal pH at Ad Lib Intake

	Animal		
	A	B	C
14% CP	5.1	5.1	5.5
RDP-Balanced	5.2	5.7	6.0

Table 2. Comparison of RDP Supply to RDP Predicted (Restricted Intake)

Corn (%)	**98**	**90.1**	**82.0**	**73.9**	**96.3**
SBM (%)		**7.9**	**16.0**	**24.1**	
Biuret (%)					**1.7**
%RDP Required	**4.2**	**3.9**	**3.5**	**3.2**	**4.1**
%RDP Supplied	**1.5**	**4.2**	**7.0**	**9.8**	**1.5**
pH	**5.6**	**5.6**	**5.7**	**5.7**	**5.7**
Ammonia, mM	**5.1**	**7.9**	**12.5**	**17.9**	**7.8**
SCFA, mM	**101**	**103**	**103**	**107**	**89**
MOEFF	**12**	**19**	**18**	**18**	**13**

Table 3. Growth Response to Roughage Removal and Balanced RDP and RUP

	SBM (14%) 10% Hay	BM	BM 10% Hay	SBM-H Pair-fed	Urea
Steers (0-84d)					
ADG	4.2	4.9	4.1	3.8	3.7
FG	5.0	3.9	4.8	5.1	5.2
Heifers (0-84d)					
ADG	3.1	3.7	3.1	3.1	3.2
FG	5.9	5.0	5.9	5.9	5.6

Table 4. Growth Response to Roughage Removal and Balanced Rumen Degradable and Undegradable Protein

	Phase One Diet Composition			Phase Two Diet Composition		
Ingredients	**FM**	**BM**	**SBM**	**FM**	**BM**	**SBM**
Whole Corn	87.45	88.45	78.50	92.85	93.15	78.50
Fishmeal	9.30	---	---	4.30	---	---
Bloodmeal	---	8.30	---	---	4.00	---
Soybean meal	---	---	9.00	---	---	9.00
Hay	---	---	10.00	---	---	10.00
Vit/Min Premix	3.25	3.25	2.50	2.85	2.85	2.50
KCl	0.70	0.70	---	0.70	0.70	---

Table 5. Growth Response to Roughage Removal and Balanced RDP and RUP

Intake and Growth

	Treatments		
Item	**FM**	**BM**	**SBM**
Initial Weight, lbs	**667**	**671**	**662**
Final Weight, lbs	**1034**	**1076**	**1032**
ADG, lbs	**3.2**	**3.5**	**3.4**
DM Intake, lbs	**16.9^{b}**	**17.7^{b}**	**19.9^{a}**
Feed to Gain	**5.3**	**5.1**	**5.8**

Table 6. Growth Response to Roughage Removal and Balanced RDP and RUP

Manure Volume

	Treatments		
Item	**FM**	**BM**	**SBM**
P1 Wet Manure Wt, kg	**112^{a}**	**117^{a}**	**271^{b}**
P1 Manure DM %	**39.6**	**35.9**	**38.7**
P2 Wet Manure Wt, kg	**151^{a}**	**162^{a}**	**268^{b}**
P2 Manure DM%	**48.4**	**42.7**	**41.0**

[a,b] Means within row with differing superscripts differ ($P < 0.05$).

Table 7. Balancing Absorbable Amino Acid Requirements

Predicted ratio of Arginine consumed to that required

Diet	Ratio
FM	1.04
BM	1.01
SBM	1.02

Table 8. Energy Prediction

	FM	BM	SBM-H
Net Energy	0.76	0.78	1.01
Effective Energy	1.00	1.00	1.13

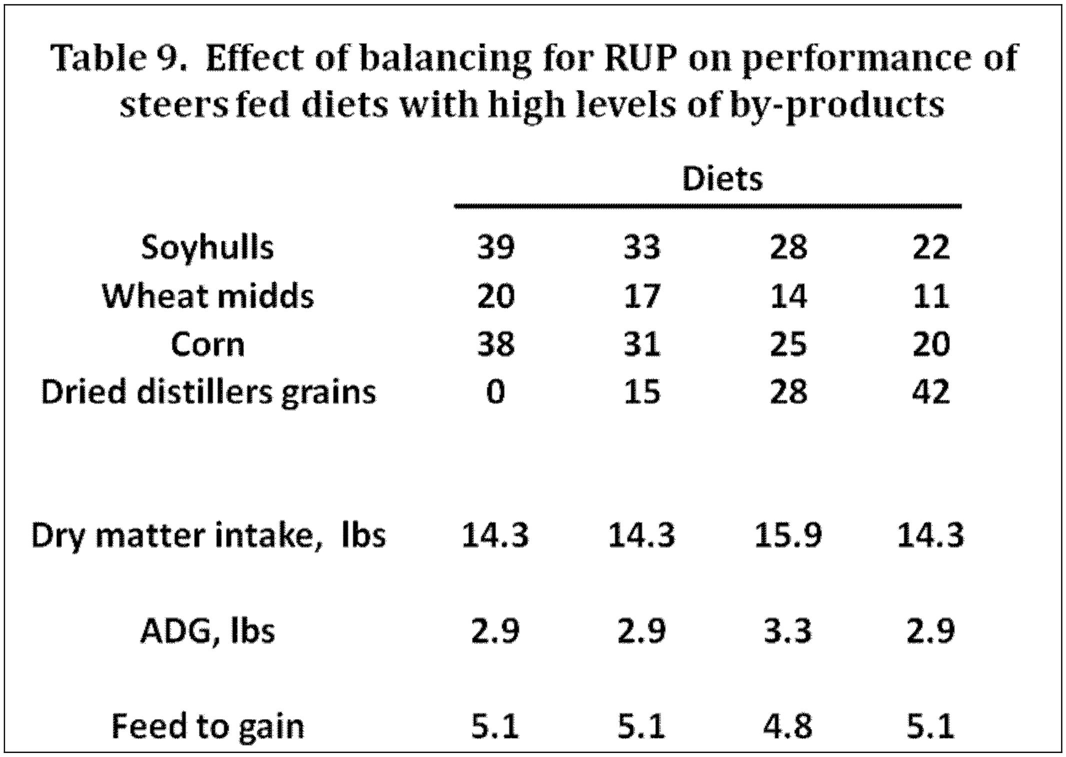

Table 9. Effect of balancing for RUP on performance of steers fed diets with high levels of by-products

	Diets			
Soyhulls	39	33	28	22
Wheat midds	20	17	14	11
Corn	38	31	25	20
Dried distillers grains	0	15	28	42
Dry matter intake, lbs	14.3	14.3	15.9	14.3
ADG, lbs	2.9	2.9	3.3	2.9
Feed to gain	5.1	5.1	4.8	5.1