FEEDING TO MEET PROTEIN FRACTIONS AND AMINO ACID NEEDS IN FEEDLOT CATTLE

A. DiCostanzo
Department of Animal Science
University of Minnesota

SUMMARY

In spite of extensive literature concerning amino acid and protein fraction utilization, and the existence of a well-researched model to predict requirements of growing and finishing beef cattle, there appears to be a resistance to leave the concept of crude protein (**CP**) for the more sophisticated method of determining requirements based on metabolizable protein (**MP**) proposed by the NRC (1996, update 2000). This is further complicated by the lack of reports indicating whether amino acid nutrition of growing-finishing cattle should be considered throughout the lifetime of the animal. The current is a review of the literature on amino acid nutrition of the young beef animal, and a report of meta-analyses conducted to test the model proposed by NRC (1996, update 2000) to balance protein fractions in diets of feedlot cattle. Limiting amino acids in diets of young, growing calves fed corn-based diets are lysine, methionine and threonine, and these are not expected to be limiting beyond 310 kg or 683 lb.. Perhaps the simplest approach to meet amino acid requirements is to first consider the level of intake without supplementation. If calves are expected to be on the high end of dry matter intake (**DMI**), likely over 2.5% of body weight, then rumen-undegradable intake protein (**UIP**) sources that best meet requirements for these limiting amino acids is recommended at the minimum required amounts. When amino acid supply post-ruminally was in excess of requirements detrimental effects on performance due to costs associated with urea synthesis were observed. Most corn and corn-co-product-based diets provide sufficient amounts of rumen-degradable intake protein (**DIP**) to meet MP requirements of fast-growing feedlot cattle. However, meta-analyses of a dataset containing experiments designed to test effects of distillers's grains and solubles (**DGS**) on performance may have provided a biased estimate of MP requirement that is 200 g/d greater than proposed by NRC (1996, update 2000) for ADG. When feeding corn and corn co-product diets, DIP fractions may be deficient; therefore, steam-flaked and ground corn diets may benefit more from inclusions of DIP.

INTRODUCTION

Since the mid 80s, and later incorporated in the mid 90s, protein needs of feedlot cattle have been expressed as protein fractions (metabolizable protein, **MP**, and rumen-degradable protein, **DIP**) instead of crude protein (Fox et al., 1992; NRC, 1985; NRC 1996 and NRC, 1996, update 2000; available at http://www.nap.edu/catalog/9791.html#toc). Yet, towards the end of the first decade of 2000, practical applications of protein nutrition of feedlot cattle remain grounded in the crude protein concept. Crude protein (**CP**; N% X 6.25) appears to remain the preferred approach as it is fairly straightforward, and CP is easily analyzed; thus the database for CP content of feeds is large and accessible to most feed companies and feedlot consultants. Similarly, little application of current knowledge in amino acid nutrition occurs in feedlot diet formulation in the field. Protein transformations in the rumen and the host animal are well understood, and an increasing body of literature exists on balancing diets of ruminant animals for amino acids (NRC, 1996; O'Connor et al., 1993; Wilkerson et al., 1993); therefore, it is not impossible to fine tune formulation procedures to balance feedlot rations on amino acids or protein fractions. In addition, increased concerns with impact of N emissions into the environment may lead further efforts to refine CP and DIP and MP requirements.

Concurrently, a surge in production of ethanol processing co-products such as distillers' grains and solubles (**DGS**) and condensed distillers' solubles (**CDS**) due to increased ethanol processing in North

America led to renewed efforts to study CP, DIP and rumen-undegradable intake protein (**UIP**) requirements of feedlot cattle. A thorough validation of the DIP and MP requirements determined by NRC (1996, update 2000) has not been conducted. Thus, the following is a validation of requirements of feedlot cattle weighing over 550 lb, and consuming corn-based and corn-co-product supplemented diets. In addition, a summary of the state of knowledge in amino acid nutrition of the lightweight Holstein calf is provided.

FEEDING TO MEET DIP AND MP OR AMINO ACIDS

It is a well known fact that the UIP fraction of corn and corn products and co-products is relatively high; therefore, MP supply in most corn-based diets is close to, or exceeds that required by feedlot cattle (Klemesrud et al., 2000b; Ludden et al., 1995; Sindt et al., 1993). When considering the effects of implant use, MP requirements for maintenance were lower in implanted than non-implanted cattle (DiCostanzo and Zehnder, 1999); further reducing the need to focus on MP balance. At the same MP intake, implanted cattle deposited more protein (have greater ADG) than non-implanted cattle (DiCostanzo and Zehnder, 1999). Implants based on trenbolone acetate (**TBA**) and estradiol or TBA and progesterone reduced protein synthesis and degradation, with a greater effect on the latter; therefore, both protein accretion and energetic efficiency of TBA-steroid implanted cattle is improved (DiCostanzo and Zehnder, 1999). Guiroy et al. (2002) demonstrated that the anabolic implant response is due to a combination of reduced maintenance requirements, reduced energy content of the gain and increased efficiency of use of absorbed energy. These observations would indicate that meeting MP requirements of feedlot cattle, particularly yearlings weighing over 310 kg (683 lb), should not be difficult with corn-based, finishing diets. Indeed, results from the studies of Klemesrud et al. (2000b), Ludden et al. (1995) or Sindt et al. (1995) demonstrated that supplementing diets with UIP-high protein sources to meet MP requirements had little or no effect on performance once cattle reached BW over 310 kg (683 lb).

Feeding to meet amino acid needs

In contrast, Holstein calves are typically procured at BW of 120 to 150 kg (265 to 330 lb) for entry into the feedlot. Therefore, nutritionists working with Holstein feeders must consider the post-ruminal amount and profile of bacterial and UIP amino acids for the period of time when Holstein calves weigh between 300 and 700 lb. Lysine, methionine and threonine are the top three amino acids likely to be deficient in corn-based diets.

During the first 112 d on feed, Holstein calves fed steam-flaked corn diets containing 0.44% urea and 4.15% feather meal or 1.35% urea supplied deficient amounts of lysine, methionine and threonine (Zinn et al., 2000). Furthermore, the diet containing 1.35% urea as the sole protein source provided deficient amounts of lysine and methionine up to 224 d on feed. In support of this observation, lysine and methionine supplementation of a corn-based diet (42.5% high-moisture and dry rolled corn and 45% wet corn gluten feed, and 5% alfalfa) improved performance (Klemesrud et al., 2000b). Crossbred steer calves (237 kg or 522 lb) fed rumen-protected lysine and methionine had improved average daily gain (**ADG**) and feed conversion during the first 56 d on feed (Klemesrud et al., 2000b). Supplementing diets with rumen-protected methionine alone had no effect on performance. A requirement of metabolizable lysine of 40.5 g/d was derived from a subsequent metabolism study (Klemesrud et al., 2000b).

Feeding Holstein calves steam-flaked corn diets supplemented with 4.5% fish meal (Zinn and Shen, 1998) more closely matched methionine and lysine requirements predicted by Zinn (1988). In the study of Zinn (1998) the ratio of observed:expected dietary NE was used as an indicator of protein adequacy. Zinn and Shen (1998) observed a quadratic relationship ($R^2 = 0.99$) between metabolizable methionine and the ratio of observed: expected dietary NE. When extrapolated to achieve a ratio of 1.0, the metabolizable methionine requirement predicted was 13.2 g/d.

Holstein steers (198 kg or 437 lb) supplemented with a blend of equal parts blood meal, meat and bone meal and feather meal at 2% of the diet DM, and 0.5% urea had a ratio of observed:expected dietary NE closest to of 0.95, while that of calves supplemented with urea (0.50%) as the only protein source had an observed:expected NE ratio of 0.88 (Zinn and Owens, 1993). Calves supplemented with urea and those supplemented with 2% blend had intestinal digestion of methionine of 13.3 and 14.5 g/d, respectively. Although methionine supply to the small intestine of calves in this study was similar to that predicted by Zinn and Shen (1998), calves fed the UIP blend had better performance. Differences in performance were greater during the first 56 d on feed, but remained for the 84-d experiment in favor of cattle fed the UIP blend at 2% of the diet DM. It appears that rumen-protected methionine may be more efficiently utilized than UIP sources. Methionine supplementation with a rumen-protected source was 50% more efficient than using feather meal (Klemesrud et al., 2000a).

Cracked-corn diets of 301-kg (664-lb) steers supplemented with soybean meal or rumen-protected soybean meal, instead of urea, had improved ADG and feed conversion during the first 28 d on feed. Enhanced performance was also observed when supplementing diets with a combination of corn gluten and blood meal improved feed conversion during the first 28 d (Ludden et al., 1995). Limiting amino acids in urea-supplemented diets were lysine, methionine, and, to a small extent, threonine. In that study, calves fed the urea supplement were estimated to have a metabolizable lysine supply of 40.0 g/d, while supplies of metabolizable lysine for calves supplemented with true protein sources were greater than 48 g/d. Discrepancies between these results and the proposed metabolizable lysine requirement of Klemesrud et al (2000b) are clear. Either co-limiting amino acid supply in urea-supplemented steers obscured the effect of a metabolizable lysine requirement or calves of this BW (301 kg vs 237 kg) have a greater metabolizable lysine requirement.

Choosing UIP sources is not as simple as trying to match amino acid requirements to amino acid profiles of UIP sources. For instance, feeding soybean meal- or urea-based supplements to 320-kg (706 lb) Holstein steers did not alter the amount of lysine, methionine or threonine absorbed from the small intestine (Cecava and Parker, 1993). Indeed, using this mixture instead of soybean meal did not alter the flow and disappearance of essential amino acids in the small intestine. However, flow and disappearance of essential amino acids improved when a corn gluten and blood meal mixture was used instead of dry corn gluten feed. Similarly, feeding cracked corn diets (>71%) supplemented with soybean meal (12.7%) or urea (1.8%) to 215-kg estradiol-treated Holstein steers (Knaus et al., 2001) led to N retentions that were greater than that measured in steers supplemented with 5.2% of an UIP source blend (porcine meat and bone meal, fish meal, hydrolyzed feather meal, and blood meal). The authors cited reduced MP derived from bacteria as the reason for reduced N utilization of UIP source blend.

In attempting to supply amino acids using UIP sources, the role of DIP supply is perhaps undervalued. A close association between DIP (diet DM basis) and microbial N flow to the duodenum was modeled (Zinn and Shen, 1998). The equation to predict microbial N flow to the duodenum is:

Microbial N flow, g/d = $25.9 + 13.7\text{DIP} - 0.66\text{DIP}^2$ (Zinn and Shen, 1998).

A minimum of 100 g DIP/kg total digestible OM (Zinn and Shen, 1998) is required to maximize rumen digestible organic matter and microbial nitrogen flow. A Holstein calf (200 kg or 440 lb) consuming 5.5 kg (12 lb) DM/d with a TDN of 82% would require 450 g of DIP (51% DIP in a 16% CP diet) to have microbial nitrogen flow maximized.

When over-supplying UIP, the cost of excreting urea may offset the benefits of supplying amino acids post-ruminally. Holstein calves fed > 2% (diet DM) of a UIP blend had poorer performance, in spite of more closely meeting their amino acid requirements, and a better ratio of observed:expected dietary NE than those fed urea (Zinn and Owens, 1993). Over-supplying UIP sources beyond a projected need, particularly when not meeting DIP requirements, may actually lead to an arginine-deficiency (caused by sparing arginine for preferential use to detoxify ammonia) or increased energy expenditure for urea synthesis.

Similarly, consideration to DMI before deciding to supplement amino acids is necessary. In the studies where the greatest response to amino acid supplementation was observed, DMI of lightweight Holstein calves averaged > 2.5% of the body weight. In contrast, where DMI was at 2.5% of the body weight, the response to amino acid supplementation was small. This may reflect either the demand on calves already present at the time the decision is made to supplement amino acid nutrition, the ability to respond to amino acid supplementation because growth potential or diet support greater intake, or both.

MEETING THE DIP AND MP NEEDS OF FEEDLOT CATTLE

Feedlot steers weighing over 750 lb responded positively to aggressive implant strategies with reduced MP requirements for maintenance (DiCostanzo and Zehnder, 1999) relative to MP requirements derived from NRC (1996). This translated to greater efficiency of conversion of protein to muscle accretion. Intake of MP was determined to be optimum at 8.04 g MP/kg$^{0.75}$/d for steers implanted with medium- and high-potency implant strategies (DiCostanzo and Zehnder, 1999). Primary dietary grain source (Block et al., 2005; Gleghorn et al., 2004; Milton et al., 1997; Shain et al., 1998) appeared to influence the response of implanted cattle to protein supplementation to meet DIP and MP fractions.

In today's world of increased supply of ethanol processing co-products there appear to be further complications in the interactions between supply of protein fractions and level of dietary crude protein. A theoretical determination of the effects of meeting both fractions by increasing dietary CP, as it occurs when corn co-products are used was plotted in Figure 1. The effects of increasing dietary CP at various DIP values (from 45% to 55% DIP on a CP basis) are reflected on the balances of both DIP and MP. At dietary CP concentrations near 15%, and assuming a daily DMI of 22.5 lb, a steer requiring 850 g MP and 790 g DIP will meet its DIP and MP requirements with diets containing as low as 50% DIP (CP basis). This may simply be the case when diets are formulated to contain 25% or more distillers' grains. DiCostanzo and Zehnder (1999) calculated the minimum dietary CP and DIP (CP basis) should be 13% and 61%, respectively, to meet MP requirements of implanted steers.

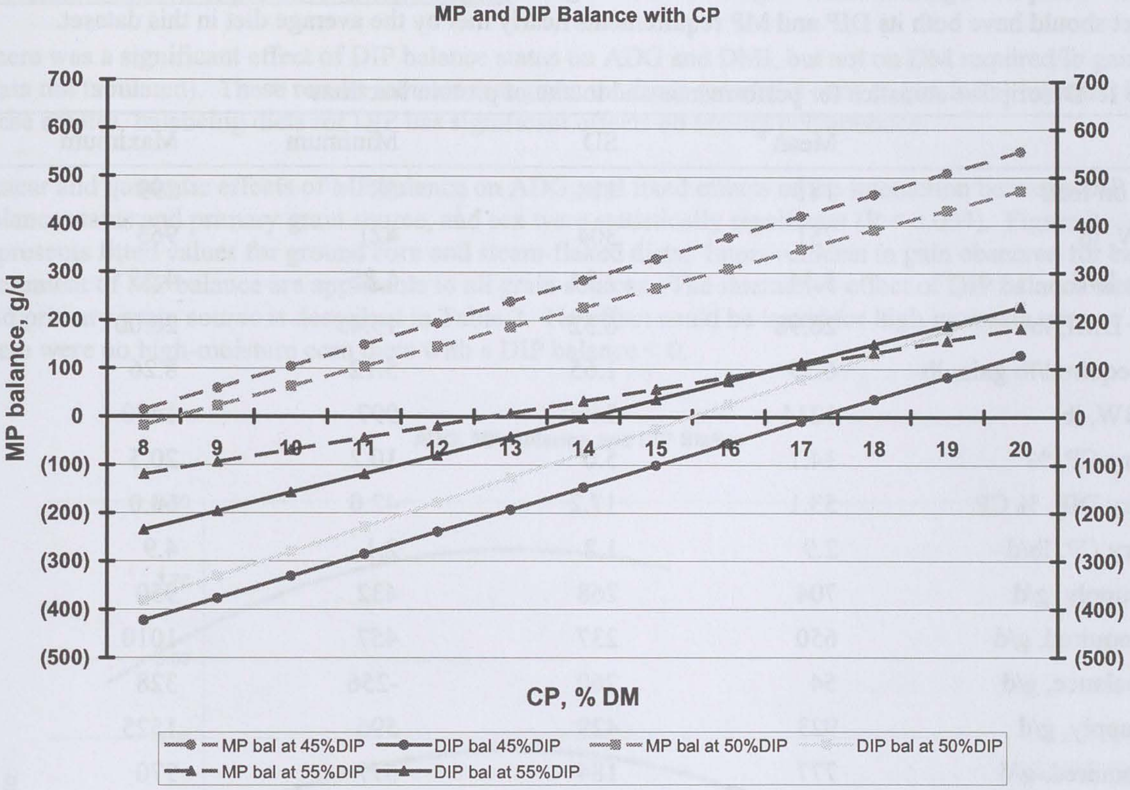

Figure 1. Metabolizable protein and rumen degradable protein balance (g/d) at various dietary crude protein concentrations for a steer consuming 22.5 lb DMI/d and requiring 850 g MP and 760 g DIP/d.

In spite of having been published over 10 years ago, few consultants if any use the NRC (1996, update 2000) to balance feedlot rations. Perhaps the program is somewhat cumbersome; but, more importantly, the question remains: does the gain in applying the requirements proposed by NRC (1996, update 2000) justify the effort?

University studies published in refereed publications and university research reports on the effects of feeding ethanol processing co-products (condensed distillers solubles and wet or dry DGS) on performance and carcass characteristics was utilized as the basis for a database submitted to a meta-analyses designed to determine the appropriateness of requirements proposed by NRC (1996, update 2000) for DIP and MP. Because studies with finely ground corn were not part of the distillers' grains data base, additional data points were included from University of Minnesota reports since 1997. Thus, the dataset contained results from studies using corn processed by various methods: finely ground, dry rolled or cracked, high-moisture or steam-flaked, and unprocessed (whole).

Statistical approaches

A total of 128 treatment means were compiled containing results of 29 studies with 719 pens and 6,362 head of cattle (Table 1). Feeding conditions were representative of cattle fed in the Great Plains and Midwest. Average initial BW, ADG, DMI and feed conversion (FTG) were: 751 lb, 3.34 lb/d, 20.98 lb/d, and 6.39, respectively, and were fed for 141 d. Dietary CP averaged 14.1% and DIP averaged

53.1%. Extrapolating from data in Figure 1, the average feedlot animal represented by the combined dataset should have both its DIP and MP requirements nearly met by the average diet in this dataset.

Table 1. Descriptive statistics for performance and intake of protein fractions

Item	Mean [a]	SD	Minimum	Maximum
Days on feed	141	114	58	299
In BW, lb	751	304	421	963
ADG, lb/d	3.34	1.34	1.85	4.55
Daily DMI, lb	20.98	6.52	15.45	26.00
DM required/lb gain, lb	6.39	1.65	5.12	8.26
Out BW, lb	1214	246	997	1450
Dietary CP, %	14.1	5.0	10.2	20.5
Dietary DIP, % CP	53.1	17.2	42.0	68.0
Dietary CP, lb/d	2.9	1.2	2.1	4.9
DIP supply, g/d	704	268	432	950
DIP required, g/d	650	237	457	1010
DIP balance, g/d	54	260	-256	328
MP supply, g/d	923	429	596	1525
MP required, g/d	777	184	577	970
MP balance, g/d	146	328	-99	609
Hot carcass wt, lb	758	144	632	914

[a] Weighted by number of pens/treatment.

Meta-analyses procedures were conducted using PROC MIXED (SAS, 1999). Briefly, initial models contained random effects of study and state origin, and regression intercept and independent variables, and were weighted by number of pens in each treatment mean. Additional fixed effects accommodated effects of sex (steers or heifers), and the primary grain source (whole, cracked, ground, high-moisture or steam-flaked corn). Degrees of freedom were calculated using the method of Kenward-Roger, and, where appropriate, means were separated using the least square procedures. Models were tested for their ability to improve over initial models using fit statistics (-2RLL, AIC, AICC, BIC). Balances predicted by NRC (1996, update 2000) software were validated by including MP balance as an independent variable, and initial weight as a covariate. To avoid modeling collinear variables, DIP balance was modeled as a fixed variable (DIP balance status: < 0 vs ≥ 0). Values for DIP and UIP supply, requirements and balance were derived using the NRC (1996, update 2000) software with adjustments for effective NDF (eNDF) and DIP values as suggested by Lardy et al. (1988). Namely, most grain and grain byproducts are assumed to contain no eNDF, except for wet DGS (corn or milo), and corn gluten feed, which are listed with 18% eNDF, and DIP values for whole, dry and high-moisture corn are assumed to be 40%, and 60% of CP. Based on this, steam-flaked and ground corn were assumed to have 40% DIP (CP basis). These adjustments correct for lower than expected microbial efficiency without the need to estimate a direct correction on the default value of 0.13 X TDN intake. Dependent variables were ADG, DMI and DM required/lb gain (analyzed as lb gain/lb DM intake).

Test and validation of protein fraction balances

There was a significant effect of DIP balance status on ADG and DMI, but not on DM required/lb gain (data not tabulated). These results indicate that given the feeds (corn and corn co-products) included in these studies, balancing diets for DIP has significant effects on feedlot performance.

Linear and quadratic effects of MP balance on ADG, and fixed effects of the interaction between DIP balance status and primary grain source, and sex were statistically significant ($P < 0.004$). Figure 2 represents fitted values for ground corn and steam-flaked diets. Improvements in gain observed for each increment of MP balance are applicable to all grain sources. The interactive effect of DIP balance status and primary grain source is described in Table 2. No effect could be tested for high-moisture corn as there were no high-moisture corn diets with a DIP balance < 0.

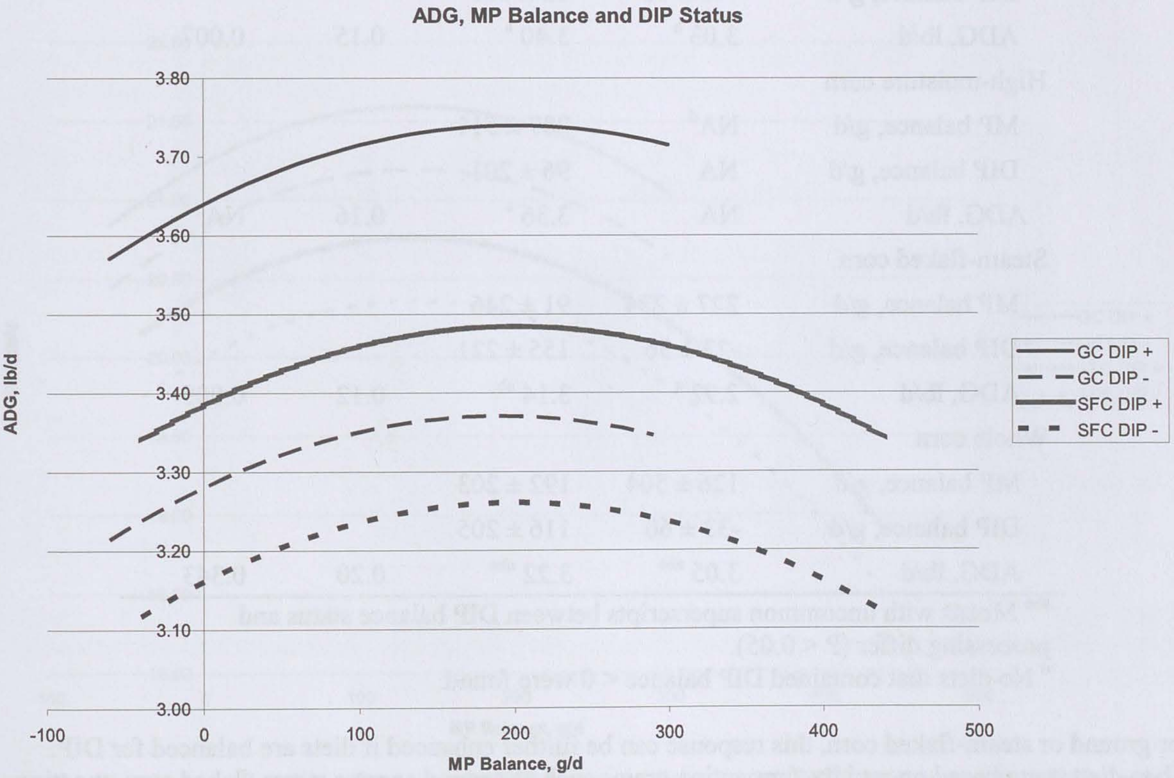

Figure 2. Fitted regression lines for ground (GC) or steam-flaked corn (SFC) in response to MP balance and DIP balance status(DIP balance < 0 vs DIP balance ≥ 0).

Exceeding MP supply over requirements resulted in increased ADG up to 200 g MP/d. Thus, exceeding MP supply 200 g over balance resulted in improvements of gain of 0.10 lb/d (Figure 2) regardless of whether DIP balance was positive or negative. Diets containing 20% to 30% DGS can easily contain from 14% to 15% CP and 45% to 50% DIP (CP basis). At DMI greater than 20 lb/d, a feedlot animal can easily take in 1,000 g MP, while requirements for MP appear to hover around 750 to 850 g/d. Therefore, ADG responses observed when feeding from 20% to 30% DGS may result from increased MP supply. On the other hand, this observation may be reflective of an upward bias, independent of a MP effect, due to the influence of DGS concentrations in the dataset.

Table 2. Least square means for effects of DIP balance status on ADG for various corn processing methods

Item	DIP < 0	DIP ≥ 0	SE	P-value
Cracked corn				
MP balance, g/d	178 ± 247	136 ± 362		
DIP balance, g/d	-79 ± 116	106 ± 168		
ADG, lb/d	3.32 ^{a}	3.33 ^{a}	0.10	0.806
Ground corn				
MP balance, g/d	142 ± 289	-5 ± 63		
DIP balance, g/d	-48 ± 76	82 ± 115		
ADG, lb/d	3.03 ^{b}	3.40 ^{a}	0.15	0.007
High-moisture corn				
MP balance, g/d	NA[d]	287 ± 511		
DIP balance, g/d	NA	96 ± 201		
ADG, lb/d	NA	3.36 ^{a}	0.16	NA
Steam-flaked corn				
MP balance, g/d	227 ± 224	91 ± 246		
DIP balance, g/d	-23 ± 56	155 ± 221		
ADG, lb/d	2.92 ^{c}	3.14 ^{ab}	0.12	0.009
Whole corn				
MP balance, g/d	126 ± 504	192 ± 203		
DIP balance, g/d	-33 ± 60	116 ± 205		
ADG, lb/d	3.05 ^{abc}	3.22 ^{abc}	0.20	0.343

[abc] Means with uncommon superscripts between DIP balance status and processing differ ($P < 0.05$).

[d] No diets that contained DIP balance < 0 were found.

For ground or steam-flaked corn, this response can be further enhanced if diets are balanced for DIP. When diets were based on rapidly-fermenting grains such as ground corn or steam-flaked corn, meeting or exceeding DIP balance resulted in improvements in gain of 0.37 and 0.22 lb/d, respectively. Weighted means of negative DIP balance for cattle fed ground and steam-flaked corn diets were -48 and -23 g/d, respectively, while those of positive DIP balance diets were 82 and 155 g/d, respectively (Table 2). This means that both ground corn and steam-flaked corn diets may require significantly greater amounts of DIP than suggested by the NRC (1996, update 2000) model. Assuming total tract OM digestibility of 78%, and OM intake of 8.2 kg/d (from Figure 4 and extrapolating from Zinn and Shen, 1998) for steam-flaked corn diets in this dataset, the amount of DIP required for maximum ruminal digestion of OM and microbial nitrogen flow (Zinn and Shen, 1998) would be 640 g/d. The weighted mean for DIP supply by steam-flaked corn diets in a negative DIP balance was 546 g/d (NRC 1996, update 2000 model projected a requirement of 569 g/d). Relative to Zinn and Shen (1998), negative DIP balance steam-flaked corn diets were 94 g/d in deficit. In contrast, steam-flaked corn diets in positive DIP balance supplied 697 g DIP/d; a value much closer than suggested by Zinn and Shen (1998). When providing adequate DIP supply, cattle fed diets based on ground or steam-flaked corn had similar ADG to those fed diets containing cracked, high-moisture or whole corn (Table 2).

If one ascribes the response to increased MP supply (under-predicted requirements by NRC, 1996, update 2000), then one would conclude that finishing diets must contain 1,000 g MP/d for optimum ADG. Under field conditions, adding CP sources to meet an additional MP supply of 200 g/d, when use of DGS is not dictated by economics of energy supply, is likely to be more expensive and cumbersome than adding additional urea to provide an additional 150 to 225 g DIP/d over requirement. Diets containing between 0.8 and 1% urea led to better performance than those containing less than 0.8% or more than 1% urea (DiCostanzo, 1995). Thus, assuming that urea concentrations in the basal diet are less than 1% of diet DM, adding an additional 0.10 to 0.18 lb urea/hd/day may alleviate this DIP deficit.

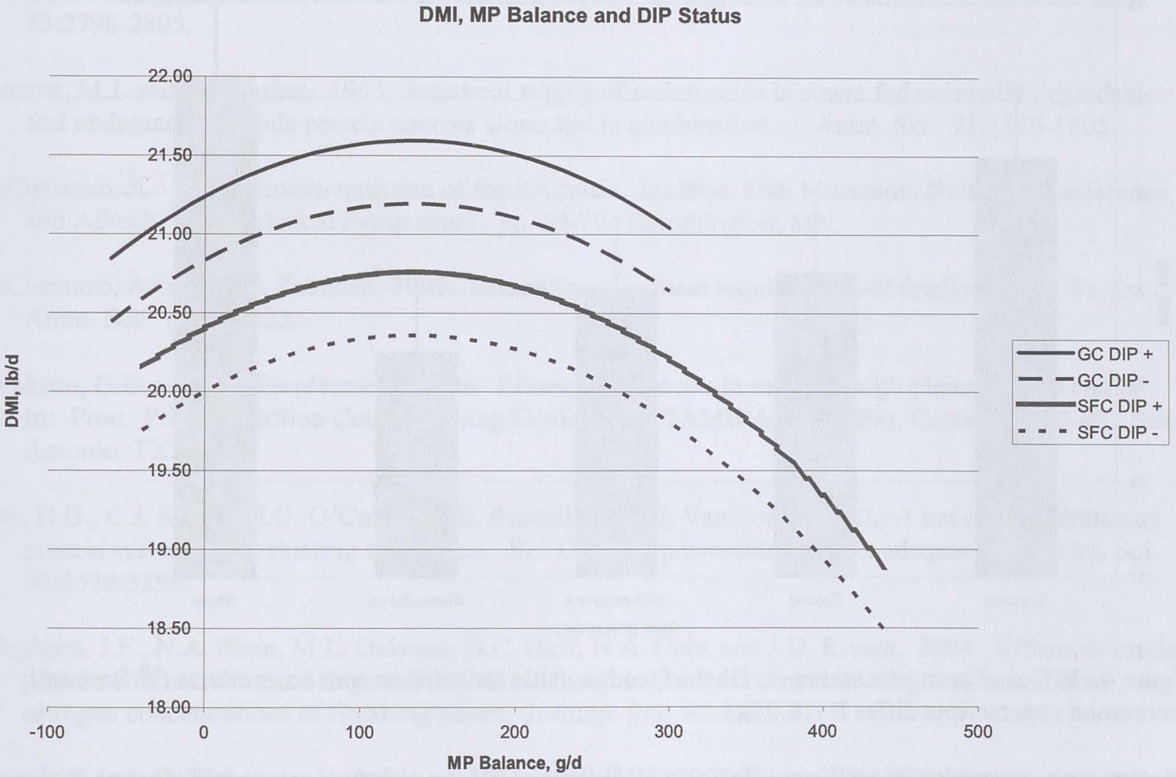

Figure 3. Fitted regression lines for ground (GC) or steam-flaked corn (SFC) in response to MP balance and DIP balance status (DIP balance < 0 vs DIP balance ≥ 0).

In the current dataset, the average urea inclusion in steam-flaked corn diets with a positive DIP balance was 0.84% of the diet DM while that in steam-flaked diets with a negative DIP balance was only 0.009% of the diet DM. Thus, adding another 0.18 lb urea to a diet containing 0.009% urea (average urea addition in steam-flaked corn diets with a negative DIP balance) at a DMI of 19 lb/d would yield a dietary urea concentration of 0.94%.

Dry matter intake was modeled (Figure 3) by MP balance and the fixed effects of DIP balance status (P = 0.03), primary grain source (P = 0.006), and sex (P = 0.14). Initial weight was permitted to stay in the model at P = 0.14. As for ADG, increasing MP balance increased DMI up to 130 g MP/d excess (Figure

3). Again, it is likely that this apparent effect of increased MP supply may only be reflective of the DMI-enhancing effect of feeding diets containing DGS. At concentrations of 20% to 30% DGS, DMI can increase from 0.6 to 1.1 lb/d (Benson et al., 2005; Erickson and Klopfenstein, 2006; Mateo et al., 2004). Similarly, feeding diets containing greater amounts of CP and MP can also lead to greater DMI. In a previous meta-analysis DiCostanzo and Zehnder (1999) demonstrated that feedlot cattle fed diets containing 13% CP consumed from 0.17 to 0.26 kg/d or 0.37 to 0.57 lb/d. At peak DMI response, cattle fed 130 g more MP/d than required consumed 0.35 lb DM/d more (Figure 3). Similarly, improving the DIP balance status from negative to positive led to improvements in DMI of 0.40 lb/d. These values are within the ranges observed by DiCostanzo (1995) and DiCostanzo and Zehnder (1999), and likely reflect a result of increased bacterial CP synthesis in the rumen (Zinn and Shen, 1998).

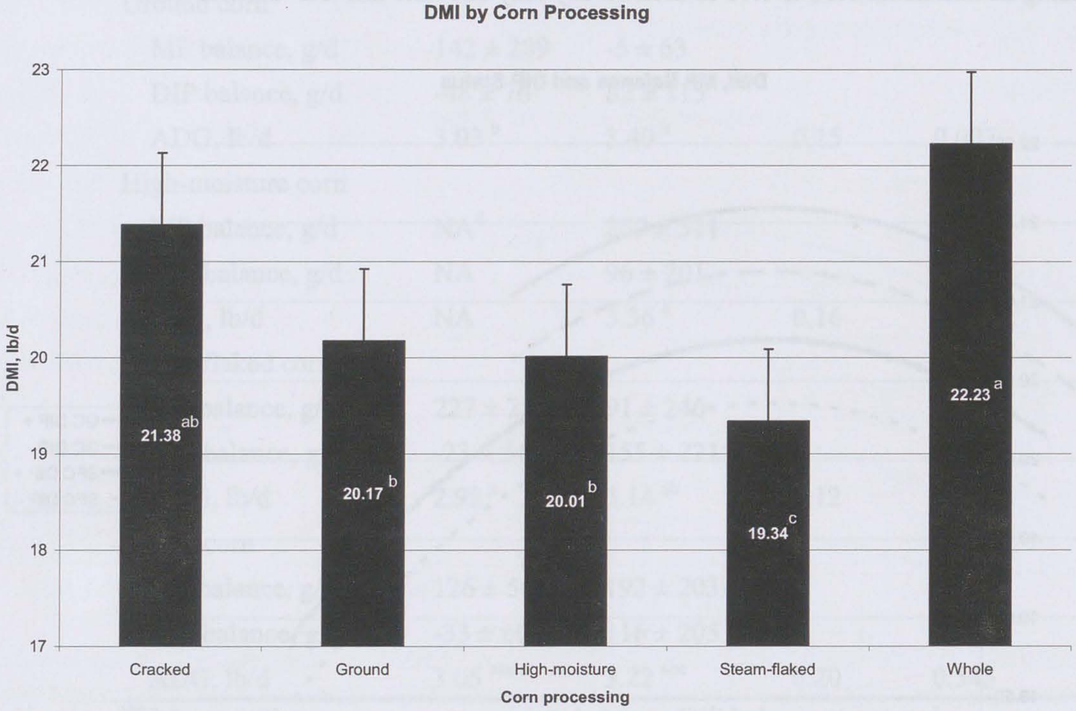

Figure 4. Effect of corn processing on DMI of feedlot cattle fed various corn co-products (^{a,b} Bars with uncommon superscripts differ $P < 0.05$).

Primary grain source had significant effects on DMI (Figure 4). As observed previously (Owens et al., 1997), cattle fed whole corn diets consumed more DM than those fed ground, high-moisture or steam-flaked corn. Cattle fed cracked corn consumed more DM than those fed steam-flaked corn, and tended ($P < 0.10$) to consume more DM than those fed ground or high-moisture corn. Previously, cattle fed steam-flaked corn diets had lesser DMI than those fed dry rolled or high-moisture corn (Owens et al., 1997). Although their data analyses did not include finely ground corn, effects of fine-grinding or steam-rolling corn on DMI may be a direct result of rapidly digested starch in the rumen, and subsequent reductions in rumen pH.

Regression of MP balance, DIP balance status, and primary grain source on DM required/lb gain was not significant. This was expected as MP and DIP balances were derived from NRC (1996, update 2000) software model. The model uses DMI and dietary eNDF, TDN, CP and DIP concentrations to determine the supply of energy and protein to meet needs of these nutrients to support ADG. Feed conversion is determined by calculation of predicted ADG and DMI. Least square means generated by analyses of fixed effects on ADG and DMI resulted in feed conversions of 6.43, 6.99 or 6.22, 6.62, 6.91 or 6.09, and

7.09 lb/lb for cracked corn, ground corn in a DIP-deficient or DIP-balanced diet, high-moisture corn, steam-flaked corn in a DIP-deficient or DIP-balanced diet, and whole corn, respectively. Efficiencies of feed conversion thus determined numerically reflect differences in feed conversion between dry rolled or high-moisture corn and steam-flaked corn reported by Owens et al. (1997).

LITERATURE CITED

Benson, C.S., C.L. Wright, K.E. Tjardes, R.E. Nicolai, and B.D. Rops. 2005. Effects of feeding varying concentrations of dry distiller's grains with solubles to finishing steers on feedlot performance, nutrient management and odorant emissions. South Dakota Ag. Exp. Sta. Beef Rep. BEEF 2005-13.

Block, H.C., C.N. Macken, T.J. Klopfenstein, G.E. Erickson, and R.A. Stock. 2005. Optimal wet corn gluten and protein levels in steam-flaked corn-based finishing diets for steer calves. J. Anim. Sci. 83:2798-2805.

Cecava, M.J. and J.E. Parker. 1993. Intestinal supply of amino acids in steers fed ruminally degradable and undegradable crude protein sources alone and in combination. J. Anim. Sci. 71:1596-1605.

DiCostanzo, A. 1995. Protein nutrition of feedlot cattle. In: Proc. 56th Minnesota Nutrition Conference and Alltech, Inc. Technical Symposium. pp. 69-79. Bloomington, MN.

DiCostanzo, A. and C.M. Zehnder. 1999. Estimation of protein requirements of feedlot steers. Prof. Anim. Sci. 15:116-123.

Erickson, G.E. and T.J. Klopfenstein. 2006. Ethanol coproducts in northern high plains feedlot cattle. In: Proc. Plains Nutrition Council Spring Conference. TAMU Ag. Res. Ext. Center. pp 40-49. San Antonio, TX.

Fox, D.G., C.J. Sniffen, J.D. O'Connor, J.B. Russell, and P.J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets. III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.

Gleghorn, J.F., N.A. Elam, M.L. Galyean, G.C. Duff, N.A. Cole, and J.D. Rivera. 2004. Effects of crude protein concentration and degradability on performance, carcass characteristics, and serum urea nitrogen concentrations of finishing steers. J. Anim. Sci. 82:2705-2717.

Guiroy, P.J., L.O. Tedesechi, D.G. Fox, and J.P. Hutcheson. 2002. The effects of implant strategy on finished body weight of beef cattle. J. Anim. Sci. 80:1791-1800.

Klemesrud, M.J., T.J. Klopfenstein, and A.J. Lewis. 2000a. Evaluation of feather meal as a source of sulfur amino acids for growing steers. J. Anim. Sci. 78:207-215.

Klemesrud, M.J., T.J. Klopfenstein, R.A. Stock, A.J. Lewis, and D.W. Herold. 2000b. Effect of dietary concentration of metabolizable lysine on finishing cattle performance. J. Anim. Sci. 78:1060-1066.

Knaus, W.F., D.H. Beermann, P.J. Guiroy, M.L. Bohem, and D.G. Fox. 2001. Optimization of rate and efficiency of dietary nitrogen utilization through the use of animal by-products and(or) urea and their effects on nutrient digestion in Holstein steers. J. Anim. Sci. 79:753-760.

Lardy, G., R. McCoy, D. Shain, T. Milton, D. Brink, and T. Klopfenstein. 1998. Use of the NRC model for predicting nutrient balances of finishing cattle. Nebraska Beef Rep. MP 69A pp 80-83.

Ludden, P.A., J.M. Jones, M.J. Cecava, and K.S. Hendrix. 1995. Supplemental protein sources for steers fed corn-based diets: II. Growth and estimated metabolizable amino acid supply. J. Anim. Sci. 73:1476-1486.

Mateo, K.S., K.E. Tjardes, C.L. Wright, T.J. Koger, and B.D. Rops. Evaluation of feeding varying levels of wet distillers grains with solubles as compared to dry distillers grains with solubles to finishing steers. South Dakota Ag. Exp. Sta. Beef Rep. BEEF 2004-03.

Milton, C.T., R.T. Brandt, Jr., and E.C. Titgemeyer. 1997. Effects of dietary nitrogen source and concentration in high-grain diets on finishing steer performance and nutrient digestion. J. Anim. Sci. 75:2813-2823.

NRC. 1985. Ruminant Nitrogen Usage. National Academy Press. Washington, DC.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th Rev. Ed. Nutrient Requirements of Domestic Animals. National Academy Press. Washington, DC.

O'Connor, J.D., C.J. Sniffen, D.G. Fox, and W. Chalupa. 1993. A net carbohydrate and protein system for evaluating cattle diets. IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298-1311.

Owens, F.N., D.S. Secrist, W.J. Hill, and D.R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. J. Anim. Sci. 75:868-879.

Shain, D.H., R.A. Stock, T.J. Klopfenstein, and D.W. Herold. 1998. Effect of degradable intake protein level on finishing cattle performance and ruminal metabolism. J. Anim. Sci. 76:242-248.

Sindt, M.H., R.A. Stock, T.J. Klopfenstein, and D.H. Shain. 1993. Effect of protein source and grain type on finishing calf performance and ruminal metabolism. J. Anim. Sci. 71:1047-1056.

Wilkerson, V.A., T.J. Klopfenstein, R.A. Britton, R.A. Stock, and P.S. Miller. 1993. Metabolizable protein and amino acid requirements of growing cattle. J. Anim. Sci. 71:2777-2784.

Zinn, R.A. 1988. Crude protein and amino acid requirements of growing-finishing Holstein steers gaining 1.43 kilograms per day. J. Anim. Sci. 66:1755-1763.

Zinn, R.A., E.G. Alvarez, M.F. Montaño, and J.E. Ramirez. 2000. Interaction of protein nutrition and laidlomycin on feedlot growth performance and digestive function in Holstein steers. J. Anim. Sci. 78:1768-1778.

Zinn, R.A. and F.N. Owens. 1993. Ruminal escape protein for lightweight feedlot calves. J. Anim. Sci. 71:1677-1687.

Zinn, R.A. and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76:1280-1289.