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Effect of corn processing on degradable intake protein requirement of finishing cattle[1]

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ABSTRACT: Three finishing trials were conducted to determine effect of corn processing on degradable intake protein requirement (DIP) of feedlot cattle. In Trial 1, 252 steers were fed 90% concentrate, high-moisture corn-based diets that contained 0, 0.4, 0.8, or 1.2% urea (DM basis) to provide dietary DIP values of 7.0, 8.2, 9.3, and 10.5% of DM, respectively. Nonlinear analysis predicted maximal feed efficiency at 10.2% dietary DIP (95% confidence interval was 9.9 to 13.3%). In Trial 2, 264 steers were fed 90% concentrate, steam-flaked corn-based diets that contained 0, 0.4, 0.8, 1.2, 1.6, or 2.0% urea (DM basis) to provide dietary DIP values of 4.7, 5.8, 7.0, 8.2, 9.3, and 10.5% of DM, respectively. Nonlinear analysis predicted maximal feed efficiency at 7.1% dietary DIP (95% confidence interval was 7.0 to 7.2%). In Trial 3, 90 individually-fed steers were fed 90% concentrate, dry-rolled, high-moisture, or steam-flaked corn-based diets. Urea was factored across diets at 0, 0.5, 1.0, or 2.0% of DM to provide dietary DIP values of 4.8. 6.3, 7.8, 9.2, and 10.7% for dry-rolled, 6.7, 8.1, 9.6, 11.1, and 12.5% for high-moisture, and 4.7, 6.1, 7.6, 9.0, and 10.5% for steam-flaked corn-based diets, respectively. For the dry-rolled corn-based diet, nonlinear analysis could not predict a requirement because feed efficiency was not improved beyond the first increment of dietary DIP, suggesting that the DIP requirement was met at 6.3% of DM. For the high-moisture corn-based diet, nonlinear analysis predicted maximal feed efficiency at 10.0% dietary DIP (95% confidence interval was 9.2 to 11.3%). For the steam-flaked corn based diet, nonlinear analysis predicted maximal feed efficiency at 9.5% dietary DIP (95% confidence interval was 9.2 to 9.5%). Our estimate of the DIP requirement for dry-rolled corn-based diets (6.3%) agrees well with past research and predicted values. Our estimate of the DIP requirement for high-moisture corn-based diets (10.1%) was very consistent between trials and higher than predicted. Our estimates of the DIP requirement for steam-flaked corn-based diets varied from 7.1 to 9.5%, with an average of 8.3% of dietary DM.

Key Words: Degradable, Intake, Maize, Processing

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Introduction

Degradable intake protein (**DIP**) is the fraction of feed crude protein that is available to the rumen microbial population. In typical diets for finishing cattle, DIP is composed of both degradable true protein and nonprotein nitrogen. A deficiency in DIP may cause a decrease in bacterial CP flow from the rumen (Tedeschi et al., 2000), possibly resulting in a metabolizable protein (**MP**) deficiency if sufficient undegradable intake protein is not supplemented. In addition, a DIP deficiency may reduce energy yield from carbohydrate fermentation (Russell et al., 1992), thereby lowering volatile fatty acid production and energetic efficiency of the diet. Therefore, a deficiency in DIP may lead to a reduction in performance of finishing cattle even when metabolizable protein requirements have been met.

Level 1 of the NRC (1996) model predicts that the DIP requirement for a typical dry-rolled corn-based finishing diet is approximately 6.8% of dietary DM. This value is supported by recent data from Milton et al. (1997b) and Shain et al. (1998). Few data exist that directly evaluate the effect of corn processing on DIP requirement. Grain processing methods that increase rate and extent of starch fermentation may increase the DIP requirement compared with dry-rolled corn. Objectives of these experiments were to determine DIP requirements of finishing cattle fed dry-rolled, high-moisture, and steam-flaked corn-based finishing diets.

Materials and Methods

Trial 1

Two hundred fifty-two crossbred yearling steers (379 kg) were used in a randomized complete block design

[1]Published with the approval of the director as paper no. 13191, journal series, Nebraska Agric. Res. Div.

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Received February 21, 2001.

Accepted August 13, 2001.

Table 1. Composition of diets (% of DM) fed in Trials 1, 2, and 3

	Diet[a]		
Ingredient	HMC	SFC	DRC
High-moisture corn	82.0	—	—
Steam-flaked corn	—	82.0	—
Dry-rolled corn	—	—	82.0
Alfalfa hay	5.0	5.0	5.0
Cottonseed hulls	5.0	5.0	5.0
Molasses	3.0	3.0	3.0
Dry supplement[b]	5.0	5.0	5.0

[a]HMC = high-moisture corn (Trials 1 and 3), SFC = steam-flaked corn (Trials 2 and 3), DRC = dry-rolled corn (Trial 3).

[b]All diets supplemented to contain a minimum of 0.7% Ca, 0.28% P, 0.6% K, and 0.15% S. All diets contained 30 mg/kg monensin and 11 mg/kg tylosin (Elanco Animal Health, Indianapolis, IN).

to determine DIP requirement of finishing steers fed a high-moisture corn-based diet. Steers were split into three initial weight blocks to minimize weight variance within a pen and assigned randomly to 12 feedlot pens. Pens were assigned randomly to one of four dietary treatments (21 steers per pen, three pens per treatment). Dietary treatments consisted of four levels of dietary DIP, which was accomplished by adding 0, 0.4, 0.8, or 1.2% urea to the base diet (DM basis). The high moisture corn-based finishing diet (**HMC**) is shown in Table 1, and dietary CP and DIP values are shown in Table 2.

High-moisture corn was harvested at approximately 29% moisture, processed through a rollermill, and stored in a covered concrete bunker. Mean particles size at the time of feeding was 722 ± 10 μm (Ensor et al., 1970). Soluble protein was approximately 46% of CP during the trial (Waldo and Goering, 1979). Steers were adapted to the finishing diet in 21 d using high-moisture corn to replace alfalfa hay (50% alfalfa for 3 d, 40% for 4 d, 30% for 7 d, and 20% for 7 d, DM basis). Cottonseed hulls were included only in the finishing diet.

Steers were weighed initially on two consecutive days after being limit-fed a 50% alfalfa:50% wet corn gluten feed diet at 2% (DM basis) of BW for 5 d to minimize fill differences. Steers were implanted with Synovex-Plus (Fort Dodge Animal Health, Overland Park, KS) on d 1 and fed for 108 d. Hot carcass weights were collected on all steers at the time of slaughter, whereas other carcass traits were collected following a 24-h chill. Final weights were calculated using hot carcass weights adjusted to a common dressing percentage (63%). Dietary NE_m and NE_g were calculated, based on performance, using the iterative procedure described by Zinn (1987).

Data were analyzed as a randomized complete block design using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit. Model effects were weight block and dietary DIP. Linear, quadratic, and cubic effects of dietary DIP were tested using orthogonal contrasts. In addition, DIP requirement was predicted by determining the breakpoint in gain/feed using the NLIN procedures of SAS.

Trial 2

Two hundred sixty-four crossbred yearling steers (355 kg) were used in a completely randomized design to determine the DIP requirement of finishing steers fed a steam-flaked corn-based diet. Steers were stratified by initial weight and randomly allotted to 24 pens so that average initial weights of pens were similar (11 steers per pen). Pens were assigned randomly to one of six dietary treatments (four pens per treatment). Treatments consisted of six levels of dietary DIP, which was accomplished by adding 0, 0.4, 0.8, 1.2, 1.6, or 2.0% urea to the base diet (DM basis). The steam-flaked corn-based finishing diet (**SFC**) is shown in Table 1, and

Table 2. Dietary protein composition and finishing performance for high-moisture corn-based diet (Trial 1)

	Treatment				
Urea, % of DM	0	0.4	0.8	1.2	SEM
Crude protein, % of DM[a]	10.6	11.8	12.9	14.1	—
DIP, % of DM[a]	7.0	8.2	9.3	10.5	—
DIP balance, g/d[a]	−19	122	262	403	—
MP balance, g/d[a]	78	90	90	90	—
DM intake, kg	12.3	12.1	12.1	12.1	0.1
Daily gain, kg[b]	1.70	1.72	1.82	1.85	0.03
Dietary NE_m, Mcal/kg[b]	1.77	1.79	1.87	1.89	0.03
Dietary NE_g, Mcal/kg[b]	1.14	1.16	1.23	1.25	0.03
Fat depth, cm[c]	0.89	0.99	0.99	1.07	0.05
Marbling score[bd]	523	507	502	493	8

[a]Based on NRC (1996) tabular values and Level 1 of NRC (1996) model. DIP = degradable intake protein. MP = metabolizable protein.

[b]Linear ($P < 0.03$).

[c]Linear ($P = 0.06$).

[d]400 = Traces 0, 500 = Small 0, 600 = Modest 0.

Table 3. Dietary protein composition and finishing performance for steam-flaked corn-based diet (Trial 2)

	Treatment						
Urea, % of DM	0	0.4	0.8	1.2	1.6	2.0	SEM
Crude protein, % of DM[a]	9.5	10.6	11.8	13.0	14.1	15.3	—
DIP, % of DM[a]	4.7	5.8	7.0	8.2	9.3	10.5	—
DIP balance, g/d[a]	–264	–135	–6	123	251	380	—
MP balance, g/d[a]	–107	–24	58	62	62	62	—
DM intake, kg[b]	10.3	10.8	11.0	11.0	11.3	11.0	0.2
Daily gain, kg[c]	1.44	1.74	2.00	2.00	2.02	2.04	0.05
Dietary NE_m, Mcal/kg[d]	1.82	1.97	2.15	2.16	2.13	2.20	0.04
Dietary NE_g, Mcal/kg[d]	1.19	1.32	1.48	1.48	1.46	1.51	0.04
Fat depth, cm[d]	0.94	1.19	1.30	1.24	1.30	1.27	0.05
Marbling score[de]	479	520	532	504	519	511	13

[a]Based on NRC (1996) tabular values and Level 1 of NRC (1996) model. DIP = degradable intake protein. MP = metabolizable protein.
[b]Quadratic ($P = 0.01$).
[c]Quadratic ($P < 0.001$).
[d]Quadratic ($P < 0.10$).
[e]400 = Traces 0, 500 = Small 0, 600 = Modest 0.

dietary CP and DIP values are shown in Table 3. Steam-flaked corn was processed to a flake density of 0.37 kg/L (29 lb/bushel) at a commercial feedlot (Hi-Gain Feedlot, Cozad, NE) and delivered to the research feedlot on a weekly basis. Mean particle size was 2,278 ± 6 μm at the time of feeding (Ensor et al., 1970). Steers were adapted to the finishing diet in 21 d using steam-flaked corn to replace alfalfa hay (40% alfalfa for 3 d, 30% for 4 d, 20% for 7 d, and 10% for 7 d, DM basis). Cottonseed hulls were included at 5% of dietary DM in all diets.

Steers were weighed initially on two consecutive days after being limit-fed a 50% alfalfa:50% wet corn gluten feed diet at 2% (DM basis) of BW for 5 d to minimize fill differences. Steers were implanted with Synovex-C (Fort Dodge Animal Health) on d 1, reimplanted with Revalor-S (Hoechst-Roussel Agri-Vet, Somerville, NJ) on d 47, and fed for a total of 129 d. Hot carcass weights were collected on all steers at the time of slaughter, whereas other carcass traits were collected following a 24-h chill. Final weights were calculated using hot carcass weights adjusted to a common dressing percentage (63%). Dietary NE_m and NE_g were calculated, based on performance, using the iterative procedure described by Zinn (1987).

Data were analyzed as a completely randomized design using the Mixed procedure of SAS. Pen was the experimental unit. Model effect was dietary DIP. Linear, quadratic, and cubic effects of dietary DIP were tested using orthogonal contrasts. In addition, DIP requirement was predicted by determining the breakpoint in gain/feed using the NLIN procedures of SAS.

Trial 3

Ninety crossbred yearling steers (278 kg) were used in a completely randomized design with a 3 × 5 factorial treatment structure to evaluate effect of corn processing on DIP requirement of finishing cattle. Steers were assigned randomly to HMC and SFC diets or to a similar diet based on dry-rolled corn (**DRC**; Table 1). Within each base diet, steers were assigned randomly to five levels of dietary DIP, which was accomplished by adding 0, 0.5, 1.0, 1.5, or 2.0% urea to the base diet (DM basis; six steers per diet per urea level). Dietary CP and DIP values are shown in Table 4. High-moisture corn and steam-flaked corn were similar to those fed in Trials 1 and 2, respectively, and dry-rolled corn was processed to a mean particle size of 2,850 ± 4 μm (Ensor et al., 1970). Visually, kernels seemed to be broken into thirds.

Steers were fed individually using Calan electronic gates (American Calan, Northwood, NH). Steers were adapted to their finishing diet by gradually increasing the amount of feed offered until steers had ad libitum intakes. Steers were offered their respective finishing diet on d 1 at 1.8% of BW (DM basis). Feed offered was then increased 0.23 kg/d (DM basis) until steers consumed feed ad libitum (approximately 21 d).

Steers were weighed initially on three consecutive days after being limit-fed a 50% alfalfa:50% wet corn gluten feed diet at 2.0% of BW (DM basis) for 5 d to minimize fill differences. Steers were implanted with Synovex-C (Fort Dodge Animal Health) on d 1, reimplanted with Synovex-Plus (Fort Dodge Animal Health) on d 67, and fed for a total of 167 d. Hot carcass weights were collected on all steers at the time of slaughter, whereas other carcass traits were collected following a 24-h chill. Final weights were calculated using hot carcass weights adjusted to a common dressing percentage (63%). Dietary NE_m and NE_g were calculated, based on performance, using the iterative procedure described by Zinn (1987).

Data were analyzed as a completely randomized design with a 3 × 5 factorial treatment structure using

Table 4. Dietary protein composition and finishing performance for steers fed diets based on dry-rolled (DRC), high-moisture (HMC), or steam-flaked (SFC) corn in Trial 3

	Treatment					
Urea, % of DM	0	0.5	1.0	1.5	2.0	SEM
Crude protein, % of DM[a]	9.5	10.9	12.4	13.8	15.3	—
DIP, % of DM[a]						
DRC	4.8	6.3	7.8	9.2	10.7	—
HMC	6.7	8.1	9.6	11.1	12.5	—
SFC	4.7	6.1	7.6	9.0	10.5	—
DM intake, kg[b]						
DRC	9.9[c]	9.6	10.0	10.6	10.4[c]	0.4
HMC	10.5[c]	9.6	9.7	9.9	9.5[d]	0.4
SFC[f]	8.1[d]	10.1	9.5	10.0	8.5[e]	0.4
Daily gain, kg[b]						
DRC[g]	1.54[c]	1.64[cd]	1.54[c]	1.80	1.68[c]	0.06
HMC[h]	1.68[c]	1.57[c]	1.60[cd]	1.70	1.51[d]	0.06
SFC[f]	1.36[d]	1.72[d]	1.69[d]	1.85	1.57[cd]	0.06
Dietary NE_m, Mcal/kg						
DRC	1.82[c]	1.98	2.04[c]	1.94	1.87[c]	0.06
HMC	1.88[c]	1.89	1.90[c]	2.01	1.86[c]	0.06
SFC	1.98[d]	1.97	2.06[d]	2.06	2.10[d]	0.06
Dietary NE_g, Mcal/kg						
DRC	1.18[c]	1.33	1.18[c]	1.29	1.23[c]	0.05
HMC	1.24[c]	1.25	1.25[c]	1.35	1.22[c]	0.05
SFC	1.32[d]	1.32	1.39[d]	1.40	1.43[d]	0.05
Fat depth, cm	1.07	1.14	1.14	1.35	1.09	0.08
Marbling score[i]	511	530	519	535	501	13

[a]Based on NRC (1996) tabular values and Level 1 of NRC (1996) model. DIP = degradable intake protein.
[b]Corn processing × dietary DIP interaction (P < 0.01).
[c,d,e]Means with unlike superscripts within a column differ (P < 0.10).
[f]Quadratic effect of urea level (P < 0.05).
[g]Linear effect of urea level (P < 0.05).
[h]Cubic effect of urea level (P < 0.05).
[i]500 = Small 0, 600 = Modest 0.

the Mixed procedure of SAS. Steer was the experimental unit. Model effects were corn processing method, dietary DIP, and the interaction of the two. Least squares means were separated using Least Significant Difference method when a significant (P < 0.05) F-test was detected. When a significant (P < 0.05) corn processing method × dietary DIP interaction was detected, linear, quadratic, and cubic effects of urea level were tested by orthogonal contrasts within grain processing method. In addition, DIP requirement was predicted by determining the breakpoint in gain/feed using the NLIN procedures of SAS. Procedures for all trials had been reviewed and accepted by the University of Nebraska Institutional Animal Care Program.

Results

Trial 1

Effects of DIP level on performance of finishing steers fed a high-moisture corn-based diet are shown in Table 2. Dry matter intake was not affected (P = 0.74) by dietary DIP and averaged 12.2 kg/d. However, ADG improved linearly (P < 0.03) as dietary DIP increased. Nonlinear analysis of gain/feed (Figure 1) predicted a breakpoint at 10.2% dietary DIP (95% confidence interval was 9.9 to 13.3%).

Trial 2

Effects of DIP level on performance of finishing steers fed a steam-flaked corn-based diet are shown in Table 3. Dry matter intake (P = 0.01) and ADG (P < 0.001) responded quadratically as dietary DIP increased. Nonlinear analysis of gain/feed (Figure 2) predicted a breakpoint at 7.1% dietary DIP (95% confidence interval was 7.0 to 7.2%).

Trial 3

Effects of DIP level on performance of finishing steers fed dry-rolled, high-moisture, or steam-flaked corn-based diets are shown in Table 4. Corn processing method × dietary DIP interactions were found (P < 0.01) for DM intake and ADG. For DRC, DM intake (P = 0.08) and ADG (P = 0.03) responded linearly with DIP level. Nonlinear analysis of gain/feed failed to converge, suggesting that the DIP requirement was met by the first increment of dietary DIP (6.3%).

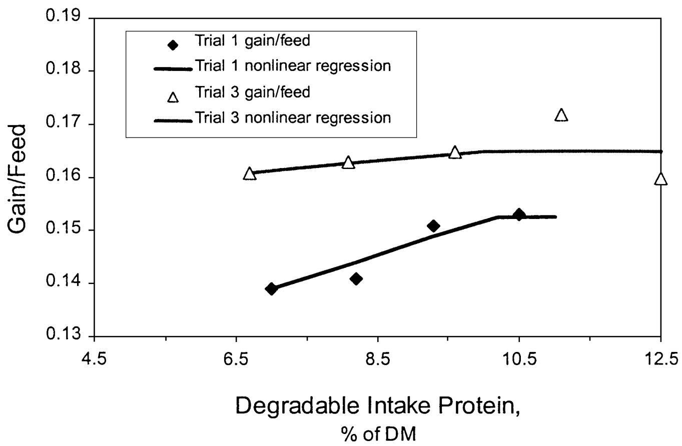

Figure 1. Estimated degradable intake protein requirements for steers fed high-moisture corn-based diets (Trials 1 and 3).

For the HMC diet, DM intake was not affected ($P > 0.10$), but ADG responded cubically ($P = 0.03$) with DIP level. Nonlinear analysis of gain/feed (Figure 1) predicted a breakpoint at 10.0% dietary DIP (95% confidence interval was 9.2 to 11.3%).

For the SFC diet, DM intake and ADG responded quadratically ($P < 0.001$) with DIP level. Nonlinear analysis of gain/feed (Figure 2) predicted a breakpoint at 9.5% dietary DIP (95% confidence interval was 9.2 to 9.5%).

Discussion

Level 1 of the NRC (1996) model predicts that finishing cattle fed a typical 90% concentrate, DRC-based diet require approximately 6.8% dietary DIP to meet requirements. Recent finishing trials with DRC-based diets generally support the DIP requirement predicted by Level 1 of the NRC model.

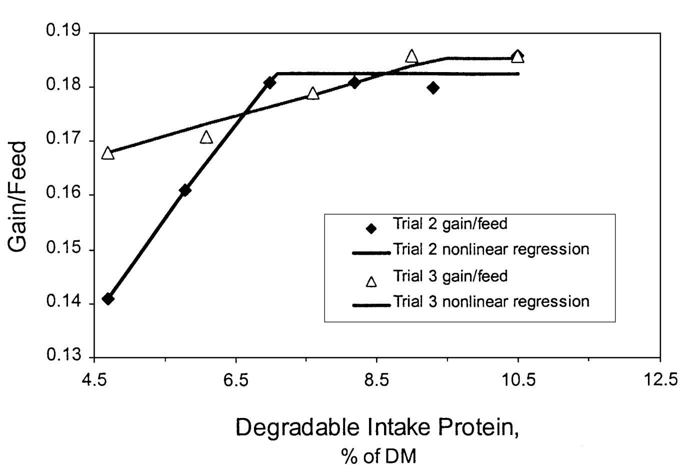

Figure 2. Estimated degradable intake protein requirements for steers fed steam-flaked corn-based diets (Trials 2 and 3).

Milton et al. (1997a) found no performance advantage in steers fed a DRC-based finishing diet with urea levels over 0.91% of dietary DM, which provided a dietary DIP of approximately 7.1% of DM. In separate finishing studies, Milton (1997b) fed DRC-based finishing diets and found maximal performance at 0.9% urea when prairie hay was the roughage source but 0.5% when alfalfa hay was the roughage source. These levels of urea (0.9 and 0.5%) provided similar dietary DIP values (6.9 and 7.2%, respectively).

Shain et al. (1998), in two finishing trials, fed DRC-based finishing diets to yearling steers with a blend of alfalfa hay and corn silage as the roughage source. They found no performance advantage to feeding urea levels above 0.88% of DM, which provided a dietary DIP of 6.4% of DM.

In Trial 3, we found no improvement in feed efficiency with dietary DIP levels greater than 6.3% of DM in steers fed a DRC-based diet, which is similar to results of Shain et al. (1998). The average of our value with those of Milton et al. (1997a,b), and Shain et al. (1998) is 6.8%, suggesting that Level 1 of the NRC (1996) model is accurate in predicting the DIP requirement for steers fed DRC-based finishing diets.

Level 1 of the NRC (1996) model predicts that the dietary DIP requirement for cattle fed a typical 90% concentrate, HMC- or SFC-based diet is approximately 7.1% of DM. This value is slightly higher than that predicted for DRC because HMC and SFC are typically given slightly higher TDN values (90, 93, and 93% for DRC, HMC, and SFC, respectively). Carbohydrate (starch) digestion in the rumen is the most accurate predictor of microbial protein synthesis and, thus, DIP requirements (Russell et al., 1992; NRC, 1996). This suggests that corn processing methods that increase the rate and extent of starch fermentation in the rumen would also increase the dietary DIP requirement.

High-moisture corn and SFC have greater ruminal starch digestibilities than DRC. Galyean et al. (1976) fed 85% concentrate, DRC-, HMC-, or SFC-based diets to steers and found ruminal starch digestibilities of 78, 89, and 83%, respectively. Huntington (1997) summarized data from 14 trials published from 1986 through 1995 on the influence of corn processing on starch digestibility and found that ruminal starch digestibilities were 76.2, 89.9, and 84.8% for DRC, HMC, and SFC, respectively. In a companion digestion study (Cooper et al., 2001), we found ruminal starch digestibilities of 76.2, 91.7, and 89.6% for DRC, HMC, and SFC, respectively. Greater ruminal starch digestion provides more ruminally available energy and, therefore, should lead to higher DIP requirements relative to DRC, assuming similar microbial N efficiencies among corn processing methods.

Estimated dietary DIP requirements for steers fed a HMC-based diet were similar in Trials 1 and 3 (10.1% of DM) and were three percentage units higher than the predicted level of 7.1%. Level of urea, approximately 1.12%, needed to attain 10.1% dietary DIP is at the high end of that commonly fed in HMC-based diets. Galyean (1996) surveyed six feedlot consultants responsible for the nutrition program for 3.6 million cattle per year and found that dietary urea levels ranged from 0.5 to 1.5% of DM but were typically lower with diets that contained HMC because of relatively high soluble N compared with DRC and SFC. Brahman et al. (1973) fed all-concentrate, HMC-based diets to steers with urea concentrations of approximately 0.4, 1.2, 1.9, and 2.7% of dietary DM. Their results suggest that 0.4% urea was sufficient in an all-concentrate, HMC-based diet. We hypothesized that the DIP for a typical HMC-based diet would be greater than the predicted 7.1% because of the large increase in ruminal starch digestion compared with DRC.

Estimated dietary DIP requirement of steers fed a SFC-based diet was 7.1% of DM in Trial 2, whereas in Trial 3, 9.5% dietary DIP was required for maximum feed efficiency. Reasons for this difference are not clear. Differences in the two trials include cattle initial BW, grain adaptation procedure, and DM intake. Steers in Trial 2 consumed approximately 18% more DM than steers fed SFC in Trial 3, which may have reduced ruminal OM digestibility (Zinn and Owens, 1983) and, thus, lowered DIP requirements. However, when expressed as a percentage of average BW, intakes were similar between Trials 2 and 3. In addition, ADG was greater in Trial 2 than in Trial 3, suggesting that the higher DMI observed in Trial 2 did not reduce OM digestibility.

A companion metabolism study conducted concurrently with Trial 3 (Cooper et al., 2001) supports requirements found in Trial 3. In this metabolism study, we found ruminal starch digestibilities of 76.2, 91.7, and 89.6 for DRC, HMC, and SFC, respectively. Regressing these ruminal starch digestibilities vs DIP requirements estimated in Trial 3 (6.3, 10.0, and 9.5%, respectively) provided a perfect relationship ($r^2 = 1.0$). Therefore, based on ruminal starch digestibility, we hypothesize that the DIP requirement for a SFC-based diet is closer to 9.5 than 7.1% of DM. However, this metabolism study found no difference in bacterial crude protein flow to the duodenum between DRC and SFC. This suggests that the DIP requirement for a SFC-based diet is not greater than that for a DRC-based diet, supporting the DIP requirement estimated in Trial 2 for SFC (7.1%). Therefore, until further research is conducted, we can only suggest that the DIP requirement for steers fed a SFC-based diet is between 7.1 and 9.5%, or an average of 8.3% of DM.

Implications

Level 1 of the NRC model is accurate in predicting dietary DIP requirements for cattle fed a typical dry-rolled corn-based finishing diet. High-moisture corn-based diets have higher dietary DIP requirements compared with DRC and predicted requirements. The DIP requirement for steam-flaked corn-based diets is less clear but seems to be intermediate between that for dry-rolled and high-moisture corn.

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