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ABSTRACT: Two finishing trials and a metabolism trial were conducted to evaluate level of supplemental degradable intake (crude) protein (DIP) in finishing diets on cattle performance, carcass characteristics, and ruminal metabolism. Finishing trials were conducted in two consecutive years using 128 crossbred yearling steers (BW = 343 ± 5 kg, Trial 1) and 176 crossbred yearling steers (BW = 375 ± 4 kg, Trial 2) in a randomized complete block design. Steers were fed dry-rolled corn diets containing urea at 0, .88, 1.34, or 1.96% (DM basis). No differences in DMI, daily gain, or feed efficiency were noted among steers receiving diets containing supplemental urea. However, steers fed diets supplemented with urea were 5.4% more efficient ($P < .01$) and gained 6.6% faster ($P < .01$) than steers receiving no supplemental urea. Metabolizable protein (MP) content of all diets exceeded the steers' requirements. However, diets containing no urea were deficient in DIP. In the metabolism trial, four ruminally fistulated steers (BW = 380 ± 22 kg) were used in a 4 × 4 Latin square design and fed (ad libitum) diets similar to those used in the finishing trials. Nitrogen intake and ruminal ammonia N concentration increased linearly ($P < .05$) with increasing level of urea supplementation. Diets containing no supplemental urea were calculated to be deficient in DIP, resulting in reduced bacterial synthesis. Results indicate that dry-rolled corn finishing diets containing no supplemental N are deficient in ruminally degradable N. Supplementing these diets with an inexpensive source of ruminally degradable N improved animal performance. However, supplementation with urea above .88% was not beneficial.

Key Words: Cattle, Urea, Protein Degradation, Performance, Metabolism, Rumen

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Introduction

Diets formulated using corn as the energy source may be deficient in degradable intake protein (**DIP**) because corn protein is considered to be approximately 60% escape (Sindt et al., 1993). Using urea as a supply of degradable intake N for ruminal bacteria is more economical than using an intact natural protein source such as soybean meal. Although urea provides no supplemental amino acids, performance of yearling cattle fed finishing diets containing either supplemental urea or other natural protein sources have shown no difference in DMI, daily gain, or feed efficiency (Clark et al., 1970; Greathouse et al., 1974; Plegge et al., 1983).

The level of DIP required for microbial protein synthesis in finishing yearling cattle is unclear. Diets containing an excess of ruminally degradable N are considered undesirable because the excess N is excreted, resulting in a net loss of N (Poos et al., 1979). However, diets deficient in ruminally degradable N have been shown to adversely affect microbial growth (Satter and Slyter, 1974; Kang-Meznarich and Broderick, 1981). A survey of consulting feedlot nutritionists indicated that many high-grain finishing diets are formulated to contain from 12 to 14% CP with limited emphasis placed on microbial requirements for DIP and the animal's requirement for metabolizable protein (**MP**) (B. Dicke, personal communication), because limited information is available regarding these requirements. Therefore, the objectives of this study were to determine the effect of supplemental DIP (from urea) on animal performance and ruminal fermentation characteristics and to determine the requirement for DIP for yearling steers fed dry-rolled corn-based finishing diets.

Materials and Methods

Finishing Trials. Two finishing trials were conducted in consecutive years to test the effect of DIP level on feed intake, daily gain, and feed efficiency.

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Table 1. Composition of diets (%, DM basis) fed in the finishing and metabolism trials

	Urea level, % of diet DM			
Ingredient	0	.88	1.34	1.96
Dry-rolled corn	79.5	79.5	79.5	79.5
Alfalfa hay	5	5	5	5
Corn silage	5	5	5	5
Molasses	5	—	—	—
Molasses-urea supplement[a]	—	5	5	5
Dry supplement	5.5	5.5	5.5	5.5
Finely ground corn	3.16	3.22	2.68	2.14
Urea	—	—	.54	1.08
Animal fat	.14	.14	.14	.14
Limestone	1.5	1.46	1.46	1.46
Potassium chloride	.38	.35	.35	.35
Sodium chloride	.22	.30	.30	.30
Trace mineral premix[b]	.05	—	—	—
Vitamin premix[c]	.02	—	—	—
Rumensin premix[d]	.02	.02	.02	.02
Tylan premix[e]	.01	.01	.01	.01
Dietary CP, % of DM[f]				
Finishing trial	8.87	11.11	12.62	14.13
Metabolism trial	8.95	11.20	12.70	14.21

[a]Contains 50.60% CP, .95% Ca, .55% P, 2.61% K, .35% Mg, .41% S, 78,925 IU of vitamin A/kg, 15,789 of vitamin D/kg, 20 IU of vitamin E/kg, 83.25 mg/kg of Fe, 37.00 mg/kg of Zn, 23.68 mg/kg of Mn, 7.40 mg/kg of Cu, 6.66 mg/kg of Mg, 5.93 mg/kg of Co, and 23.35 mg/kg of I.
[b]Contains 10% Mg, 6% Zn, 2% Mn, 4% Fe, .5% Cu, .3% I, and .05% Co.
[c]Premix containing 15,000 IU of Vitamin A per gram, 3,000 IU of Vitamin D per gram, and 3.75 IU of vitamin E per gram.
[d]132 g monensin/kg premix.
[e]88 g tylosin/kg premix.
[f]Based on actual CP values for dry-rolled corn, alfalfa hay, and corn silage.

Trials were conducted using 128 crossbred yearling steers (mean BW = 343 ± 4.6 kg, Trial 1) and 176 crossbred yearling steers (mean BW = 375 ± 3.8 kg, Trial 2) in a randomized complete block design. Steers were blocked by weight and allotted randomly within block to one of four treatments (four replications/treatment). Treatments consisted of urea addition of 0, .88, 1.34, or 1.96% (DM basis) to the final diet to attain calculated CP levels of 9.7, 12.0, 13.5, or 15.0%, respectively. All diets contained (DM basis) 79.5% dry-rolled corn, 5% corn silage, 5% alfalfa hay, and 5.5% dry supplement (Table 1). The remaining 5% consisted of molasses for steers receiving no supplemental urea or a molasses-urea supplement for the remaining diets. Additional urea needed above the amount supplied from the molasses-urea liquid supplement was added to the dry supplement. All diets were formulated to contain .7% calcium, .3% phosphorus, .7% potassium, 27.5 mg/kg monensin (Elanco Animal Health, Indianapolis, IN), and 11.0 mg/kg tylosin (Elanco Animal Health). Samples of individual feedstuffs were collected at 7-d intervals during the study. Samples were dried in a forced-air oven at 60°C for DM determination (AOAC, 1984), ground (1-mm screen), subsampled, and analyzed for N content by macro-Kjeldahl method (AOAC, 1984).

All steers were fed common grain diets while adapting to the final treatment diets. Dietary treatments were implemented following a 28-d, five-step grain adaptation period. Diets used during the grain adaptation period consisted of adjusting the ratio of dry-rolled corn to forage (alfalfa hay and corn silage) to obtain diets containing a forage:concentrate ratio of 45:55, 35:65, 25:75, 15:85, and 7.5:92.5. All diets contained 5% molasses-urea liquid supplement and 5.5% dry supplement (same supplement as used in the .88% urea treatment).

Steers were weighed initially on two consecutive days after being fed a 50% alfalfa hay:50% corn silage diet at 2% (DM basis) of BW for 5 d to reduce fill differences. Bunk space was adequate for all steers to consume feed concurrently. Following the 28-d adaptation period, steers were weighed on two consecutive days to determine performance during the grain adaptation period. Daily gain for treatments was calculated based on average initial weight taken at the start of the adaptation period and final weight at slaughter. Final weight was based on hot carcass weight, taken at slaughter, adjusted to a common 62% dressing percentage.

Steers were fed for ad libitum intake once daily in outdoor pens (bunk space = 95 cm per animal) and were fed their final diets for an average of 93 (Trial 1) and 81 d (Trial 2). In Trial 1, steers were implanted with Compudose® (Elanco Animal Health), whereas in Trial 2, steers were implanted with Revalor-S®

(Hoechst-Roussel, Somerville, NJ). Steers were slaughtered by replication when 70% of the steers were estimated to grade Choice, by visual appraisal. Hot carcass weight and liver score were recorded at slaughter. Livers were scored for abscesses according to Brink et al. (1990). Fat thickness (12th rib), quality grade, and yield grade were obtained after carcasses were chilled for 48 h.

Requirements and supply for MP and DIP were calculated for each pen using the NRC evaluation model (1996). The supply of MP and DIP were calculated using values (percentage of CP) for dry-rolled corn, alfalfa hay, and corn silage of 40 (average of values listed in NRC, 1985 [35] and 1996 [45]), 72 (NRC, 1996), and 77% (Sindt et al., 1993) for DIP, respectively. The protein of molasses, molasses-urea supplement, and urea were considered to be 100% DIP.

Data for animal performance and carcass traits were analyzed as a randomized complete block design using the GLM procedure of SAS (1985). The model included block, treatment, and trial with residual used as the error term. Pen was used as the experimental unit. Treatment means were tested for urea level × trial interactions. If no urea level × trial interaction existed, data were pooled across trials. In diets containing supplemental urea, means were computed and sums of squares were partitioned to test for linear and quadratic effects using the GLM procedure of SAS (1985). If no linear or quadratic effects within diets containing urea were found then treatment means for diets containing supplemental urea were contrasted against diets containing no urea using an orthogonal contrast (SAS, 1985).

Metabolism Trial. This trial was conducted to verify that increasing level of urea in diets fed in the finishing trials increased ruminal ammonia N concentration and to determine the effect of increasing level of urea on ruminal pH and VFA. Four ruminally fistulated steers (mean BW = 380 × 22 kg) were used in a 4 × 4 Latin square design. Treatments consisted of diets containing either 0, .88, 1.34, or 1.96% supplemental urea, which were similar to diets used in Trials 1 and 2. Surgical and postsurgical care procedures followed those outlined by Stock et al. (1990), and all procedures had been reviewed and accepted by the University of Nebraska Institutional Animal Care Program. Steers were housed in 1.5- × 2.4-m individual slotted-floor pens in a 25°C temperature-controlled room.

Steers were adapted to treatment diets using a grain adaptation regimen similar to that used in Trials 1 and 2. Steers were fed once daily at 0800 and allowed ad libitum access to feed and water. Steers were assigned randomly to treatments in period 1. Dietary treatments were assigned in subsequent periods so that steers decreased in dietary urea level, with steers switching from no urea supplementation to the high level of urea supplementation. This was done to minimize carry over of recycled N from the body urea pool. Each period consisted of a 13-d adaptation period to treatment diets and 1 d of sample collection. Ruminal fluid samples were collected every 4 h starting at 0800 on d 14 using the suction strainer technique (Raun and Burroughs, 1962). After the last collection of ruminal fluid, ruminal contents were evacuated, weighed, mixed thoroughly, and subsampled for DM determination. Ruminal contents were placed back into steers, and the next period was initiated. Ruminal fluid samples (200 mL) were immediately measured for pH, using a combination electrode, and then frozen (−20°C) for further analysis. Ammonia N (NH_3 N; McCullough, 1967) was measured using automated procedures (Technicon Industrial Systems, Elmsford, NY). A subsample of ruminal fluid was deproteinized with 1/4 volume of 20% *m*-phosphoric acid (Erwin et al., 1961) containing 25 m*M* 2-ethyl butyrate added as an internal standard for VFA analysis. Ruminal VFA were separated and quantified by GLC (Hewlett-Packard, Avondale, PA) containing a packed (10% SP1200/1% H_3PO_4 on Chromosorb W/AW; Supelco, Bellefonte, PA) glass column and equipped with a flame ionization detector. Samples of ruminal contents and diets were dried in a forced-air oven at 55°C for DM determination. Samples of refused feed were freeze-dried, ground (1-mm screen), and analyzed for DM (AOAC, 1984) and N content by macro-Kjeldahl method (AOAC, 1984). Although individual hourly samples were analyzed, statistical analyses were performed on mean values. Data were analyzed statistically using procedures for a 4 × 4 Latin square design (Steel and Torrie, 1980). Main effects of treatment, steer, and period were included in the model with residual used as the error term. In diets containing supplemental urea, means were computed and sums of squares were partitioned to test for linear and quadratic effects using the GLM procedure of SAS (1985). If no linear or quadratic effects within diets containing urea were found, treatment means for diets containing supplemental urea were contrasted against diets containing no urea using an orthogonal contrast (SAS, 1985).

Results and Discussion

Dietary CP concentrations were less than formulated due to a lower than expected CP value for dry-rolled corn. Diets were formulated using a 10.1% CP (DM) value for corn. However, actual CP values for dry-rolled corn used in the finishing trials and metabolism trial were 8.7 and 9.0% (DM), respectively. Actual dietary CP values obtained in these trials are listed in Table 1.

Finishing Trials. No year by treatment interaction was observed ($P > .10$); therefore, data were pooled across years. No difference ($P > .10$) in DMI, daily

Table 2. Effect of urea level on pooled (across years) finishing steer performance and carcass characteristics

	Urea level, % of diet DM				
Item	0	.88	1.34	1.96	SEM
No. of pens	8	8	8	8	
Daily DMI, kg	11.58	11.88	11.64	11.78	.18
Daily gain, kg[a]	1.43	1.54	1.50	1.55	.03
Gain/DMI[a]	.123	.130	.128	.131	.002
Daily N intake, g[ab]	164	211	235	266	3
Carcass characteristics					
Hot carcass wt, kg	326	334	330	335	5
Fat thickness, cm	.91	.93	.93	.96	.03
Quality grade[c]	18.8	19.1	18.7	19.0	.2
Yield grade	2.4	2.5	2.5	2.5	.08

[a]Diet with no urea vs diets containing urea, $P < .05$.
[b]Diets containing .88, 1.34, or 1.96% urea, linear, $P < .05$.
[c]Quality grade; 18 = High Select, 19 = Low Choice.

gain, or feed efficiency were noted among treatments during the grain adaptation period (data not shown), indicating steers responded similarly to common diets fed. Therefore, subsequent performance due to treatments was not influenced by performance during the adaptation period.

No difference in DMI, daily gain, or feed efficiency ($P > .10$) was noted among steers fed diets containing urea, indicating supplementation with urea above .88% of the diet had no effect (Table 2). Steers fed diets containing urea gained faster ($P < .01$) and 5.4% more efficiently ($P < .01$) than steers fed diets containing 0% urea (Table 2). However, no difference in DMI was observed between urea-supplemented and 0% urea treatment groups. In addition, no difference in hot carcass weight, fat thickness, quality grade, or yield grade was noted among treatments.

Results similar to ours were reported by Milton and Brandt (1994a, 1995), who found that adding either .35 or .5% urea to dry-rolled corn finishing diets containing either 10% alfalfa hay or 10% prairie hay, respectively, improved daily gain and feed efficiency. Although these levels of urea addition (.35 and .5%) are below the minimum urea inclusion of .88% used in this study, Milton and Brandt (1994a, 1995) used regression analysis to determine that the optimum level of urea addition for gain and feed efficiency was between .5 and .9% of the dietary dry matter. In addition, Thomas et al. (1984) found that .7% supplemental urea added to a 60% cracked corn:30% cottonseed hull diet improved daily gain and feed efficiency of steers compared with diets containing no supplemental urea.

The NRC (1996) Level 1 model was used to predict MP requirement and supply (Table 3) and indicated that the MP content of all diets was adequate in meeting the animals' requirement. The MP requirement for steers used in the finishing trials was 737 g/d, based on steers fed diets containing 1.96% urea, gaining 1.55 kg/d. Sindt et al. (1993) estimated that the amount of escape N (percentage of total N) of dry-rolled corn in finishing diets was approximately 60%. Therefore, the amount of MP supplied from corn protein (80% of escape; NRC, 1996) would provide more than 50% of the animals' MP requirement. The remainder of the animals' MP requirement should be provided by bacterial protein.

Bacterial growth is largely dependent on the amount of ammonia and fermentable organic matter present in the rumen (Bryant and Robinson, 1962). High-concentrate finishing diets provide a source of readily fermentable carbohydrates. However, the percentage of DIP supplied from high-concentrate diets may not supply the microbes with an adequate amount of DIP or N. In the finishing trials, DIP supplied from diets containing 1.34 or 1.96% urea exceeded the microbial requirement (Table 3). Steers fed diets containing .88% urea were predicted to be deficient in DIP (−61 g/d); however, data for daily gain and feed efficiency from these steers do not indicate a deficiency. The model used to calculate the amount of DIP supplied (NRC, 1996) assumes no net recycling of N to the rumen. Steers fed the .88% urea diet possibly recycled enough N to offset this small deficiency or the DIP requirement might be slightly less than estimated by the model. Diets containing no urea were calculated to be very deficient in DIP (−312 g/d). The NRC (1985) equation for N recycling illustrates as percentage of dietary protein decreases, percentage of recycled N (as a percentage of intake protein) increases. However, in highly productive animals, tissue synthesis may act as a N sink reducing urea synthesis, and therefore less urea might be recycled to the rumen (NRC, 1985). In addition, the NRC (1996) rumen simulation model (Level 2), which estimates a net amount of recycled N, indicated that only steers fed diets containing no urea were deficient in supplying microbes with adequate N for microbial protein synthesis (Table 3).

Table 3. Calculated requirements and availability for metabolizable protein, degradable intake protein, bacterial nitrogen balance, and percentages of degradable intake protein and undegraded intake protein supplied in diets used in the finishing trials

	Urea level, % of diet DM				
Item	0	.88	1.34	1.96	SEM
Metabolizable protein, g/d					
Requirement[a]	705	733	720	737	9
Available[b]	943	973	947	955	15
Difference	239	239	227	218	14
Degradable intake protein, g/d[c]					
Requirement	795	827	801	808	13
Available[ad]	483	762	927	1,125	12
Difference[ad]	–312	–61	126	317	2
Bacterial N balance, g/d[ade]	–33.9	6.1	28.4	51.7	.3
Degradable intake protein					
% of Diet DM	4.2	6.4	8.0	9.5	—
% of Diet CP	47.1	57.7	63.0	67.2	—
Undegradable intake protein					
% of Diet DM	4.7	4.7	4.7	4.6	—
% of Diet CP	52.9	42.3	37.0	32.9	—

[a]Diet with no urea vs diets containing urea, $P < .05$.
[b]Value calculated assuming degradable intake protein (DIP) requirements are met. Value will be lower when DIP supplied is below the requirement.
[c]Calculated from Level 1 of NRC (1996) model.
[d]Diets containing .88, 1.34, or 1.96% urea, linear, $P < .05$.
[e]Calculated from Level 2 of NRC (1996) model. Values are in units of N rather than protein as in Level 1 for DIP.

Burroughs et al. (1975) suggested that limiting growth of ruminal microbes by restricting dietary DIP would reduce digestion of dietary energy (starch). Stern and Hoover (1979) indicated that the optimal ruminal ammonia N concentration required for maximal rate of ruminal fermentation may not necessarily equate to maximal microbial protein synthesis. Milton and Brandt (1994b) found that ruminal digestibility of OM and starch increased with .5% urea addition, with no change in microbial protein production. Furthermore, the efficiency of microbial protein synthesis can decline significantly at pH values less than 6.0 (Strobel and Russell, 1986). The deficiency in DIP noted in our study possibly caused a reduction in microbial protein synthesis, and possibly a subsequent reduction in ruminal digestion of dietary starch.

The percentage of DIP supplied in diets containing .88% supplemental urea was 6.4% of the diet (DM basis) or 57.7% of the diet CP (Table 3). Further increases in the amount of DIP supplied had no effect on animal performance.

Metabolism Trial. Increasing the level of urea in the diet had no effect on DMI, ruminal DM contents, or mean ruminal pH among treatments (Table 4). Daily N intake and mean ruminal ammonia N concentration increased linearly ($P < .01$) as urea level increased in diets containing supplemental urea. The increasing amount of ruminal ammonia N with increasing levels of urea addition in this study is consistent with several reports (Satter and Slyter, 1974; Mehrez et al., 1977; Kang-Meznarich and Broderick, 1981; Milton and Brandt, 1994b). Increasing level of urea had no effect on ruminal pH, ruminal VFA concentration, acetate/propionate ratio, or molar proportions of acetate, propionate, or butyrate. However, Milton and Brandt (1994b) reported a linear decrease in ruminal pH and molar proportion of butyrate and a linear increase in total VFA concentration as level of urea increased.

The concentration of ruminal ammonia N necessary for optimal ruminal digestion on various diets is not well defined. The ruminal ammonia N concentration for steers fed diets containing no urea (1.65 mg/dL) was well below levels recommended to optimize ruminal digestion (Satter and Slyter, 1974; Kang-Meznarich and Broderick, 1981). However, the ruminal ammonia N concentration of steers fed diets containing .88% urea (3.89 mg/dL) seemed to be adequate and is in agreement with levels reported by others. Kang-Meznarich and Broderick (1981) found no improvement in ruminal DM digestion when ruminal NH_3 N levels exceeded 3.33 mg/dL in 75% ground corn diets. Milton and Brandt (1994b) found no difference in total tract or ruminal digestibility of organic matter or starch with ruminal NH_3 N levels above 3.07 mg/dL. Ortega et al. (1979) determined in

Table 4. Effect of urea level on ruminal characteristics in the metabolism trial

	Urea level, % of diet DM				
Item	0	.88	1.34	1.96	SEM
Daily DMI, kg	9.13	8.56	8.15	9.14	.49
Ruminal DM, kg	4.17	3.87	3.42	4.25	.31
Ruminal pH	6.01	5.96	5.83	5.93	.09
N intake, g/d[ab]	113	138	140	192	11
Ruminal NH_3 N, mg/dL[ab]	1.65	3.89	5.99	7.89	.96
Total VFA, m*M*	119.9	112.3	122.9	117.7	4.2
Molar proportions, %					
Acetate	53.1	54.8	53.9	54.0	1.6
Propionate	41.8	38.8	40.9	39.5	1.8
Butyrate	1.7	2.1	1.9	2.5	.2
Acetate:propionate	1.3	1.5	1.5	1.5	.2

[a]Diets containing .88, 1.34, or 1.96% urea, linear, $P < .05$.
[b]Diet with no urea vs diets containing urea, $P < .05$.

situ that increasing ruminal NH_3 N concentration from 6.3 to 27.5 mg/dL did not change rate of ruminal fermentation. In contrast, optimal ruminal NH_3 N concentration for maximal rate of barley fermentation in situ has been reported as 23.5 mg/dL (Mehrez et al., 1977) or in vivo as 22.8 mg/dL (Wallace, 1979). However, Erdman et al. (1986) indicated that the concentration of ruminal NH_3 N needed for maximum digestion is a function of the fermentability of the diet, and, therefore, diets containing grain sources differing in fermentation rates may not require the same ruminal NH_3 N concentrations.

The low ruminal ammonia N concentration found in the metabolism trial and reduction in daily gain and feed efficiency noted in the finishing trials for steers fed diets containing no urea would indicate that these diets were deficient in DIP. The NRC (1996) model, in calculating the amount of MP supplied from these diets, assumes that a deficiency in the amount of DIP supplied from the diet will be corrected for by supplementation. In the finishing trials, steers fed diets containing no urea were apparently deficient in DIP. Therefore, the amount of MP supplied was possibly diminished due to a reduction in bacterial protein synthesis. Kang-Meznarich and Broderick (1981) found that bacterial protein synthesis was reduced 21% when ruminal NH_3 N concentration fell from 3.33 to 1.33 mg/dL, and Milton and Brandt (1994b) found that microbial N flow was not improved with ruminal NH_3 N concentrations above 3.07 mg/dL. Calculating the actual amount of MP supplied in diets containing no urea is difficult in this study. However, results from these trials indicate corn-based finishing diets containing less than 6.4% DIP (percentage of dietary DM) reduced animal daily gain and feed efficiency.

Implications

High-concentrate finishing diets consisting of corn, alfalfa, and corn silage provide more metabolizable protein than is necessary to meet the requirement for finishing yearling steers. However, these diets are deficient in degradable intake protein (DIP) and may reduce bacterial growth and cause a reduction in ruminal digestion and subsequent reduction in animal gain and feed efficiency. Using an inexpensive source of DIP (such as urea), rather than an expensive natural protein source (such as soybean meal), will meet the microbial nitrogen requirement. However, feeding an excess of DIP, from urea, will not improve animal performance and may cause excessive nitrogen excretion and ammonia volatilization into the environment.

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