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Protein Levels in Beef Cattle Finishing Diets: Industry Application, University Research, and Systems Results¹

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ABSTRACT: Consulting nutritionists were surveyed to determine current formulation and management practices for finishing beef cattle. Among the six consultants surveyed, percentage of CP in finishing diets ranged from 12.5 to 14.4%, with urea levels ranging from .5 to 1.5% of DM. Finishing diets were based primarily on highly processed, rapidly fermented grains (steam-flaked and high-moisture grain), with roughage levels ranging from 3 to 11% of DM. All six consultants considered feed bunk management to be a critical factor affecting feed intake and performance; five of the six consultants used aggressive implant programs based on estrogen + trenbolone acetate. Recent university research was reviewed with respect to CP level and source in finishing diets. Finishing cattle managed on aggressive implant programs seem to respond to higher levels of CP better than would be expected from the factorial calculation approach. Moreover, improvements in performance noted in recent research seemed to be more consistent

when supplemental CP was derived from ruminally degraded vs undegraded sources. Calculation of protein requirements with a metabolizable protein (MP) system yielded estimates of protein needs by finishing cattle that agreed more closely with current industry practices than did calculation based on the factorial method. The difference between the MP system and the factorial method was primarily a result of accounting for microbial N needs in the MP system. Reasons for production responses to CP levels that are greater than those calculated by the factorial method include increased accretion of protein by rapidly growing, implanted cattle, particularly during the initial phase of the finishing period, alleviation of a microbial N deficiency, and ruminal and systemic effects of ruminally degraded N on acid-base balance of beef cattle fed rapidly fermented, high-grain diets. Reasons for production responses to supplemental CP need further research.

Key Words: Beef Cattle, Crude Protein, Concentrate Diets, Rumen, Nitrogen Metabolism

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Introduction

The complex, dynamic nature of protein nutrition in ruminants is well established (NRC, 1985). Unique features of ruminant N digestion and metabolism require not only consideration of the tissue protein and amino acid needs of the ruminant animal, but also of the N metabolism and requirements of the microbial population inhabiting the digestive tract, particularly the rumen. Extensive, often exquisite,

experimentation during the last two decades has increased basic knowledge in ruminant N metabolism greatly. Nonetheless, the factorial method of calculating the quantity of CP required by growing and finishing beef cattle has been the basis for calculating requirements (NRC, 1984). Alternative systems have been proposed (NRC, 1985), and the latest revision of the *Nutrient Requirements of Beef Cattle* (NRC, 1996) uses a metabolizable protein (MP) system to calculate protein requirements. Practical diets for growing and finishing cattle typically are formulated on the basis of percentage of CP, with little effort to consider ruminal N transactions and(or) the protein/amino acid requirements of the host ruminant. This is not to suggest that the beef cattle feeding industry has remained static in dealing with protein nutrition. On the contrary, the industry has modified dietary CP concentrations over time; current diets often provide a far greater percentage of CP than predicted to be needed from the factorial equations of NRC (1984).

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These increases in CP concentration by the industry may have been capricious, based solely on anecdotal evidence. Conversely, increases in CP concentration by the industry may have been an educated response to changes in feeding and management that may modify needs for N by the microbial population and(or) by rapidly growing beef cattle fed high-concentrate diets. This review will attempt to document the current situation that exists in the beef cattle feeding industry with respect to dietary CP concentration in finishing diets, to compare that situation to recent research findings, to evaluate current practices relative to systems for calculating the protein requirements of beef cattle, and to offer biological explanations for current industry practices.

Industry Conditions

To assess current practices in the feedlot industry, six consulting nutritionists were surveyed (Table 1) regarding general management and formulation practices and specific practices with respect to percentages of CP and urea used in finishing beef cattle diets. All six consultants hold a Ph.D. degree in Animal Nutrition and service feedlots in Arizona, Kansas, Oklahoma, Nebraska, and Texas. Four of these consultants (A, B, D, and F) were considered independent, providing consulting services on a fee basis for various commercial feedlots. The remaining two consultants (C and E) are employed by commercial cattle feeding businesses and provide consulting services for the feedlots owned by the corporation. In total, these six consultants are responsible for the nutrition program of approximately 3.6 million cattle per year (Table 1). The majority of the cattle serviced by these consultants were classified as yearlings (C:Y in Table 1), which represent cattle that would be expected to be fed a finishing diet for approximately 110 to 180 d. In effect, the calf:yearling ratio more appropriately reflects days on feed than cattle age per se. Calves were deemed to be those animals on feed more than 180 d. Corn was the predominant grain fed in the feedlots served by these consultants, with milo second. Wheat and barley were only fed when price allowed their use in least-cost formulation approaches and availability was not limiting. Grain in finishing diets formulated by these consultants typically was processed, most commonly by steam flaking. Dry-rolled and high-moisture grains were not the sole grain in the diet; they were fed either in combination with each other or in combination with steam-flaked grain. Roughage concentrations varied among feedlots within consultants, with a range of 3 to 11% of the dietary DM. Sources of roughage included wheat straw (Consultant C; 3% of DM), corn silage, alfalfa hay, and sudangrass hay. Depending on the feedlot, roughages were used in combination (e.g., corn silage

Table 1. Results of a survey of consulting nutritionists regarding general management practices and percentages of crude protein and urea in beef cattle finishing diets

Consultant	No. of cattle ^a	C:Y ^b	Grains fed ^c	Grain proc. d	Rough. level, % ^e	Bunk mgmt. f	Iono. g	Implant prog. h	CP level, % ⁱ	Urea level, % ^j	Escape form. k
A	550	40:60	C,M,W,B	SF	8-11	Clean	Yes	Aggr.	13.8-14.4	1.25-1.4	No
B	1,100	33:67	C,M,W,B	HM,DR,SF	4-9	Clean	Yes	Aggr.	13-13.7	.9-1.2	No
C	150	50:50	C,M	SF,DR	3-8	Clean	Yes	Mod.	12.5-13	.7-.9	No
D	900	20:80	C,M,W	SF,DR	7-10	Clean	Yes	Aggr.	13-14	.8-1.3	No
E	400	30:70	C,M	SF,HM	9-10	Clean	Yes	Aggr.	13.5-14	1-1.5	No
F	500	50:50	C,M,W,B	SF	10	Clean	Yes	Aggr.	13-14	.5-1	No

^aValues are × 10³/yr.

^bC:Y = approximate ratio of calves (C); cattle on feed for approximately 180 d or greater) to yearlings (Y; cattle on feed for approximately 110 to 180 d).

^cGrains fed, ranked from left to right by order of use. C = corn; M = milo; W = wheat; B = barley.

^dGrain processing methods used, ranked from left to right by order of use. SF = steam-flaked; HM = high-moisture harvested and stored; DR = dry-rolled.

^eRange in roughage levels in finishing diets on a DM basis.

^fBunk management approach. In "clean" bunk management, the objective is for the feed bunk to be empty or "slick" within a daily feeding cycle.

^gIonophore used in finishing diet.

^hImplant program. Aggr. = aggressive, which for yearling steers is defined as an estrogen implant initially and an estrogen + trenbolone acetate implant within 80 to 90 d of slaughter.

ⁱMod = moderate, which for yearling steers is defined as two estrogen implants during the feeding period.

^jRange in percentage of CP in the finishing diet on a DM basis.

^kRange in percentage of urea in the finishing diet on a DM basis.

^lFormulation for escape protein.

and alfalfa hay) or were fed alone (e.g., all hay or all silage).

The use of "clean" bunk management was consistent among the six consultants (Table 1). This bunk management approach represents an effort to have no feed remaining in the bunk at the end of a daily feeding cycle. Some variance was evident in application of this bunk management approach, with Consultant A striving for clean feed bunks by 2400 to 0200; others were only concerned with the daily feeding cycle. All six consultants were unanimous in their belief that consistency in the time of feed delivery to the bunk was a critical feature of bunk management. Moreover, all six consultants believed that the use of a clean bunk management approach ultimately stimulated greater feed intake by cattle than bunk management programs that allowed feed to accumulate in the bunk. Several of the consultants indicated that employees responsible for making feed bunk calls (amount of feed per pen) used guidelines for feed intake and were provided with historical records (7- to 14-d data or averages) of intake by each pen of cattle. Efforts to standardize feed bunk management represent a significant portion of the time each consultant spent within a given feedlot, indicating the importance placed on this area by consulting nutritionists.

All six consultants included an ionophore in the finishing diet (Table 1), typically at a concentration equal to or slightly less than the maximum legal concentration. Five of the consultants used implant programs that were classified as aggressive (Table 1). An aggressive program was defined for yearling steers as an estrogen implant at the start of the feeding period, followed by a combination estrogen + trenbolone acetate implant within 80 to 90 d of the projected slaughter date. For heifers, an aggressive implant program consisted of an initial estrogen implant, followed by a trenbolone acetate implant within 80 to 90 d of slaughter combined with melengestrol acetate in the feed. The moderate implant program used by consultant C consisted of an initial estrogen implant, followed by reimplantation with a second estrogen implant.

The overall values for formulated percentage of CP (DM basis) in the finishing diet ranged from 12.5 to 14.4% (Table 1). Obviously a considerable portion of the total CP beyond that supplied by the dietary ingredients was derived from urea, which ranged from .5 to 1.5% of dietary DM. When higher-protein grains such as wheat or barley were fed, the same total dietary CP concentration was used, so less protein was added. In addition, most of the consultants indicated that urea concentrations typically were lower with diets that contained high-moisture corn; the soluble N contribution from high-moisture corn is greater than with steam-flaked or dry-rolled sources. None of the six consultants formulated for escape protein. The consistent response among the consultants was that

they believed that escape protein formulation may be important in some circumstances but that insufficient information was available to allow for use of this factor when formulating diets.

Results of the present survey agree with those of a survey of 12 consulting nutritionists conducted for the University of Nebraska in 1994 (personal communication, B. D. Dicke, Cattlemen's Consulting Service, Lincoln, NE). Dicke reported that the range in CP concentrations used in finishing diets was 12.5 to 13.8% (average = 13.1%), with a range in urea levels of .8 to 1.5%.

Responses by the six consultants in the present survey indicate several important factors with respect to evaluation of nutritional practices in the beef cattle feeding industry and evaluation of research data on protein nutrition of ruminants. First, the typical finishing diet has a low roughage level and is composed largely of well-processed grain. Second, these consultants believed that feed bunk management is an important component of an overall nutrition program. Third, implant programs used by the beef cattle feeding industry in the Great Plains and Southwest feeding areas tend to be aggressive, with implants used for maximum gain and feed efficiency. Finally, as will be noted in a subsequent section, CP concentrations are greater than would be predicted by the NRC (1984) system for determining the protein requirements of beef cattle, and urea typically contributes a significant portion of the supplemental N in beef cattle finishing diets. This summary of factors from this consultant survey will be used as a guide for evaluating university research data in the next section.

University Research

Research data related to CP concentrations in beef cattle finishing diets were reviewed for those cases in which experimental conditions approximated the current industry situation. Hence, I considered only those experiments in which the dietary roughage level was low (approximately 10% or less) and aggressive implant programs were used. Unfortunately, few university research facilities have the ability to process grain as extensively as commercial feedlots. As a result, many of the experiments I reviewed used dry-rolled grain as the major ingredient in the diet rather than steam-flaked or high-moisture grain. In addition, most of the experiments reviewed were taken from published reports of conferences, Agricultural Experiment Station publications, and published abstracts; relatively few recent experiments that relate to industry conditions have been published in peer-reviewed journals.

Implant × Protein Level Experiments. Estrogenic and/or androgenic implants, by increasing accretion of protein by cattle, could affect dietary protein

requirements. Byers et al. (1994) used comparative slaughter methods and carcass specific gravity to evaluate effects of no implant and various implant combinations in crossbred yearling steers fed 85% concentrate (steam-flaked corn) diets. Implant treatments included initial Synovex S (Fort Dodge Anim. Health, Overland Park, KS; 200 mg of progesterone and 20 mg of estradiol benzoate) + Finaplix S (Hoechst-Roussel Agri-Vet, Somerville, NJ; 140 mg of trenbolone acetate) implants, followed by Synovex S at d 56, an initial Synovex S implant followed by Synovex S + Finaplix S at 56 d, or initial Synovex S + Finaplix S implants, followed by Synovex S + Finaplix S at 56 d. Daily empty body gain was 1.21, 1.49, 1.66, and 2.06 kg/d for the control and three respective implant treatments, with daily protein gains of 138, 200, 255, and 322 g, respectively. Implant treatments decreased the percentage of fat in the gain but not the total quantity of fat gained per day. Similar findings were noted by Hutcheson and Johnson (1994), who used six sets of four cloned, Brangus calves fed an 85% concentrate diet to evaluate no implant, an androgen implant, an estrogen implant, and a combination androgen + estrogen implant on body composition (grinding and chemical analysis of the left side). Steers implanted with the androgen + estrogen implant had greater empty body protein gain (91.7 g/d) than those implanted with the estrogen implant (68.3 g/d), androgen implant (63.3 g/d), and nonimplanted steers (36.7 g/d). Daily empty body weight gain was not reported for this study. As in the study of Byers et al. (1994), the quantity of empty body gain of fat per day did not differ among implant treatments.

Trenkle (1992, 1993a,b,c, 1994a,b) conducted a series of experiments to evaluate effects of implant programs and protein level/source in beef cattle finishing diets. In the first two experiments (Trenkle, 1992, 1993a), 126 large-framed Continental crossbred steers were fed a 90% concentrate (cracked corn) diet. Dietary protein levels for the first 85 d of the feeding period were 9.5 and 11%, with all supplemental N from urea, and 12.5% and 14% with supplemental N from a combination of urea and soybean meal. Cattle in the 9.5, 11, and 12.5% CP groups were either implanted with Synovex S + Finaplix S or not implanted, whereas all cattle fed 14% CP were implanted. After 85 d, cattle were assigned to 11 or 14% CP diets and either implanted or not implanted with Synovex S + Finaplix S or Synovex S alone (11% CP only) and fed for an additional 112 (Trial 1) or 90 d (Trial 2). In both trials, nonimplanted cattle did not gain as rapidly as implanted cattle, nor did they respond to CP levels above 11% during the first 85 d on feed, whereas gain by implanted steers increased as dietary CP increased. Implanted cattle fed 14% CP during the first 85 d gained 8% more than implanted cattle fed 12.5% CP, with a 5% improvement in feed:gain ratio at 14% CP in the two trials. In the 90- to 112-d period, the second phase of these two

experiments, feeding implanted steers 14% CP diets increased gain (9.9%), DMI (8.6%), and improved feed:gain (1.7%) compared with implanted steers fed 11% CP diets. Carcass data were not markedly altered by CP treatments, with a tendency for greater fat thickness and larger longissimus muscle area in cattle fed 14% than in those fed 11% CP.

Trenkle (1993b) compared protein levels and sources in diets for British-breed and Continental-cross yearling steers in a 111-d feeding trial. Dietary treatments were 88% concentrate (cracked corn) diets with 11.5% CP (supplemental N from urea) or two, 14% CP diets (supplemental N from urea + soybean meal or corn gluten feed). Steers fed 11.5% CP were either implanted with Revalor S (Hoechst-Roussel Agri. Vet; 24 mg of estradiol 17- β + 120 mg of trenbolone acetate) or not implanted, whereas all steers fed 14% CP diets were implanted with Revalor S. Increasing CP from 11.5 to 14% improved gain (13%) and feed:gain (2.7%) of implanted steers. Within 14% CP diets, steers fed urea + soybean meal gained 13.4% faster and consumed 7% more DM than those fed corn gluten feed. Trenkle (1994a) fed 144 crossbred (British \times British) yearling steers diets formulated to contain 11.5% CP (supplemental N from urea), 12.9 and 13.9% CP (supplemental N from urea + corn gluten meal + blood meal), or 14% CP (supplemental N from urea + soybean meal). Across the 11.5, 12.9, and 13.9% CP diets, steers either were implanted with Revalor S or not implanted, whereas all steers fed the 14% CP urea + soybean meal diet were implanted with Revalor S. Diets with supplemental CP from corn gluten meal and blood meal did not affect performance by either implanted or nonimplanted steers; however, the soybean meal + urea diet increased ($P < .05$) daily gain and tended ($P < .10$) to improve feed:gain by implanted steers compared with the other protein levels and sources. Implants tended to lower the percentage of Choice carcasses; this effect was not moderated by increased dietary CP. Effects of an increased CP level on performance were less evident in an experiment (Trenkle, 1994b) with Continental-cross, large-framed steer calves fed the same treatments (11.5, 12.9, 13.9, and 14% CP diets; implanted or not implanted with Revalor S) for 204 d. Performance responses to increased protein were noted during the first 70 d of the trial, but steers fed lower CP levels compensated for initially lower gain in the latter portion of the feeding period. Decreased carcass quality grade with implants was noted only for cattle fed supplemental CP of low ruminal degradation.

In finishing yearling heifers (medium- to large-framed), increasing the dietary CP concentration in 90% concentrate, cracked corn diets from 9.5 or 11.5% (supplemental N from urea) to 14% (supplemental N from soybean meal + urea) increased daily gain and feed intake over a 107-d feeding period by both implanted (Synovex H; Fort Dodge Anim. Health +

Finaplix H; Hoechst-Roussel Agri. Vet) and nonimplanted heifers (Trenkle, 1993c). Negative effects of implanting on carcass quality grade tended to be offset by the 14% CP level.

Bartle and Preston (1994) evaluated effects of estradiol + trenbolone acetate implants on performance by crossbred steers (initial BW = 312 kg) in response to protein level and source. Treatments included diets with 11.8, 13.5, or 15.3% CP (supplemental N from urea, blood meal, and corn gluten meal), a treatment in which CP level started at 15.3%, was decreased in 35 d to 13.5%, and decreased to 11.8% after an additional 35 d, followed by withdrawal of all supplemental protein, and a continuous 13.5% CP treatment in which all supplemental CP was supplied by urea. Diets were based on steam-flaked milo, and all steers were reimplanted on d 70 of the experiment. Implants increased gain by 27% and gain:feed by 18%; percentage of Choice carcasses was decreased from 59 to 47% by implanting. With nonimplanted steers, CP level did not markedly affect daily gain or gain:feed, but increasing CP level increased gain and gain efficiency among implanted steers. Performance was not affected by decreasing CP level up to 105 d on feed but was adversely affected by withdrawal of supplemental CP. Providing 13.5% CP from all urea was as effective as the combination of urea, corn gluten meal, and blood meal.

Not all experiments have shown responses to increasing CP level in implanted finishing cattle. Brandt et al. (1994), in a study conducted at multiple sites, reported no effects of increasing CP from 11.5% (supplemental N from urea) to 12.7 and 13.9% (supplemental N from corn gluten meal and blood meal) on performance by finishing steers fed for 99 to 116 d. Implants increased daily gain by 24% and DMI by 5.5%, but CP level did not interact with implant.

Dietary N Level and Source Experiments. Hancock et al. (1994) fed 128 steers a 60% corn silage:30% high-moisture corn grower diet (12.7% CP) for a 56-d period, followed by a 15% corn silage:85% high-moisture corn finishing diet (11% CP). Steers were implanted or not implanted with Revalor S, and supplemental CP was provided either as urea, soybean meal, a ruminal escape soybean meal, or a 50:50 mix of soybean meal and ruminal escape soybean meal. Compared with urea-supplemented diets, supplemental soybean meal sources increased daily gain (22%) and gain:feed (9%) of implanted but not of nonimplanted steers during the growing phase. Moreover, daily gain and gain:feed increased linearly with increasing ruminal escape protein during the finishing phase. During finishing, both implanted and nonimplanted cattle responded to supplemental escape protein. Preston et al. (1993) fed Revalor S-implanted steers diets with various CP levels and sources. The basal diet of 10.5% CP was supplemented with either cottonseed meal to provide 13% CP, cottonseed meal + urea to provide 15% CP, or cottonseed meal + ruminal

escape protein sources to provide 15% CP. Treatment with somatotropin was factored across CP levels and sources. For the 98-d experiment, gain and gain:feed were increased ($P < .05$) by increasing CP level. Gain and DMI were greater with the 15% CP cottonseed meal + urea diet than with the 13% CP cottonseed meal diet, with an intermediate response to the 15% CP cottonseed meal + ruminal escape protein diet. Response in gain:feed to somatotropin tended to increase with increasing dietary CP level. Milton and Brandt (1994a) compared urea and soybean meal as supplemental CP sources in 11.5 and 13.5% CP diets of steers implanted with Revalor S. A fifth dietary treatment of 13.5% CP with supplemental CP from cottonseed meal also was included in the experiment. Increasing urea to supply 13.5% CP tended to decrease DMI and decreased daily gain, whereas increasing soybean meal to supply 11.5 vs 13.5% CP increased gain. Cottonseed meal resulted in performance similar to that attained with soybean meal. Trenkle (1995b) supplemented high-concentrate, cracked corn diets (13.3% CP) of Revalor S-implanted yearling steers with 2.1% urea, 10% alfalfa, or 10% soybean meal. Supplemental soybean meal and alfalfa increased DMI compared with urea, and supplemental soybean meal increased gain compared with urea; performance with supplemental alfalfa was intermediate. Milton et al. (1995) noted no effect on gain or gain:feed of medium-framed, crossbred steers (implanted with Revalor S) from adding two percentage units of dietary CP from either a 50:50 combination of blood meal and corn gluten meal or soybean meal to 90% concentrate diets with the basal CP supplied by either soybean meal or urea. Steers fed urea consumed more DM, but were less efficient than those fed soybean meal as the basal source of supplemental CP. Likewise, Thomson et al. (1995) fed Revalor S-implanted, finishing beef steers a 90% concentrate (steam-flaked milo) diet with 11, 12, or 13% CP. Four sources of supplemental CP included a blood meal:corn gluten meal mix, cottonseed meal, soybean meal, and urea. Daily gain, DMI, and gain:feed increased linearly with increasing CP level, but CP source did not affect performance. Source of CP also had minimal effects on carcass characteristics. Secrist et al. (1995) noted no effect of increasing CP level with supplemental soybean meal from 12.5 to 13.5% in 92% concentrate, high-moisture corn-based diets for Synovex S/Revalor S-implanted steers. The higher CP level tended to negatively affect performance during the second half of the experiment, and the authors concluded that supplemental CP needs of high-moisture corn diets are affected by non-protein N contributed by high-moisture corn.

Several recent experiments have compared combinations of natural protein sources and urea and varying urea levels in beef cattle finishing diets. Healy et al. (1995) compared a negative control diet with four, 13% CP, steam-flaked corn diets in which the

supplemental CP was derived from combination of soybean meal and urea (100:0, 67:33, 33:67, and 0:100). Daily gain and gain:feed responded quadratically to supplemental CP source, with optimum gain and gain:feed at the 67:33 and 33:67 combinations of soybean meal and urea. In two trials with Revalor S-implanted calves (140 d on feed) and yearlings (133 d on feed), Trenkle (1995a) compared an 11.5% CP, urea-based finishing diet with 14% CP diets in which supplemental CP was supplied by urea or combinations of soybean meal and urea. Greatest gains and optimum feed:gain were noted with combinations of soybean meal and urea (5 or 10% soybean meal with 1.22 or .55% urea) compared with urea alone, and decreasing dietary CP to 11.5% at 56 d for yearlings and 62 d for calves did not markedly affect performance or carcass characteristics.

Shain et al. (1994) fed crossbred yearling steers a 92.5% concentrate (dry-rolled corn) diet with 9.7, 12, 13.5, or 15% CP using graded levels of urea to increase the dietary CP concentration. Daily gain was increased by the first level of urea addition (12% CP), but no further improvements were noted with additional urea. Milton and Brandt (1994b) fed 90% concentrate diets with urea added at 0, .5, 1, or 1.5% of DM to medium-framed, crossbred steers (dietary CP ranged from 9.9 to 13.9%). Daily gain and gain:feed responded quadratically to urea level, with the maximum response to the first increment of urea. Regression analysis indicated that the optimum urea level was .91% of DM for gain and gain efficiency. In a companion digestion/metabolism experiment (Milton and Brandt, 1994c), increasing urea level increased ruminal OM and starch digestibility quadratically, with no effect of urea level on total tract starch digestion. True ruminal and total tract N digestibility increased linearly with increasing urea level. Zinn (1995) fed Holstein steers graded levels of urea (0, .4, .8, and 1.2% of DM; 10.5, 11.5, 12.5, and 13.5% CP, respectively) in steam-flaked barley diets. Increasing urea level resulted in a linear increase in daily gain and DM intake during the 84-d study. In a companion digestion/metabolism experiment, ammonia N flow to the duodenum increased linearly with added urea, whereas microbial N flow increased quadratically (greatest microbial N flow with .8% urea). Ruminal starch digestion increased linearly with urea level, as did total tract starch digestion.

Calculation of Protein Requirements

Based on current industry conditions described previously, dietary CP levels in beef cattle finishing diets typically are 12.5% or greater. Results of recent university research data generally support these industry CP levels, particularly when aggressive implant programs are used and rapidly fermented grains are fed. In addition, responses to CP levels in

excess of 12% in the majority of the university research trials were noted most often with sources of CP that are high in ruminal degradation compared with ruminal escape sources. As noted earlier, one objective of this review is to compare current CP formulation practices with expectations based on available systems for calculating dietary protein requirements of beef cattle. To address this objective, data from a recent experiment conducted at the author's laboratory were used to evaluate protein requirements of finishing beef cattle using two systems. The two systems used were the factorial approach suggested by NRC (1984) and the MP approach suggested by NRC (1996). Data used in the calculations are shown in Table 2. These data represent the main-effect performance means for large-framed steers fed a monensin/tylosin-containing diet (Malcolm-Callis et al., 1995). Results of the comparison and associated calculations are shown in Table 3.

Table 2. Evaluation data used to compare protein requirements calculated with factorial and metabolizable protein systems

Item	Description ^a
Diet information	91% concentrate; steam-flaked milo base Dry roughage (alfalfa + sudangrass hays) 2% added fat (yellow grease) Monensin (33 mg/kg) and Tylosin (11 mg/kg) NE _m = 2.15 Mcal/kg; NE _g = 1.47 Mcal/kg TDN = 87.2% ^b Effective NDF = 11.02% ^c DIP = 6.58% ^d CP = 14.5% (analyzed) Urea = 1% (formulated)
Animal information	Large-framed, British × Continental steers All cattle received a single Synovex S implant initially, and two-thirds received a second Synovex S implant after 84 d on feed Estimated BW at 28% body fat = 555 kg Average days on feed = 133 d Initial shrunk BW = 322 kg ^e Final shrunk BW = 538.3 kg ^e Average shrunk BW = 430.15 kg Frame equivalent empty BW = 330.1 kg ^f Shrunk weight gain = 1.62 kg/d Empty body gain = 1.55 kg/d ^g DMI = 9.24 kg/d

^aAll dietary percentages and concentrations are expressed on a DM basis. Dietary NE_m and NE_g values were calculated from NRC (1984).

^bCalculated from dietary NE_m concentration: TDN, % = 23.8573 × NE_m + 2.3974 × NE_m² + 24.7761.

^cCalculated values in the Cornell Net Carbohydrate and Protein System (CNCPS) described by Sniffen et al. (1992).

^dDIP = degraded intake protein. Calculated from values in the CNCPS described by Sniffen et al. (1992).

^eShrunk BW values were calculated as unshrunk BW × .96.

^fCalculated as described by NRC (1996) as frame equivalent BW × .891, where frame equivalent BW = shrunk BW × (478/555).

^gCalculated as described by NRC (1996) as shrunk weight gain × .956.

In the NRC (1984) publication, protein requirements are calculated by summing four factors that account for protein loss and(or) deposition. Metabolic fecal N and net protein deposited in the gain are the major factors, in this example 88.8% of the total of all four factors (Table 3), with smaller losses accounted for by endogenous urinary N and scurf. Dietary CP requirements are calculated by correcting for true digestibility (90%) and a biological value of absorbed amino acids of 66% (NRC, 1984), yielding for the data in Table 2 a requirement of 969.22 g of CP/d, or 10.49% of the actual DMI of 9.24 kg/d. Dietary intact vs non-protein N can be calculated from regression relationships provided by NRC (1984). In the example in Table 3, of the total CP, 7.08% should be intact protein. Hence, 3.41% of the total dietary CP could be derived from NPN, which equates to 1.19% urea on a DM basis.

With the MP system of NRC (1996) publication, protein requirements are subdivided into animal and

microbial components. Animal requirements for maintenance MP are a function of BW, and for this example, slightly less than the sum of metabolic fecal N, endogenous urinary N, and scurf components of the factorial approach (358.92 g of MP for maintenance vs 373.57 g of metabolic fecal N, endogenous urinary N, and scurf). Net protein in gain is calculated in the same manner as NRC (1984), with MP for gain subsequently calculated as a function of net protein in gain and frame equivalent empty BW (NRC, 1996). For microbial needs, microbial CP is calculated as a function of TDN intake, with an adjustment for dietary effective NDF content (Sniffen et al., 1992). For this example, microbial CP synthesis was calculated to be 839.87 g/d, which equals the amount of degradable intake protein (**DIP**) that would need to be supplied to meet microbial N needs.

The next step in the MP system is to combine estimates of animal needs for MP and microbial supply of MP for calculation of dietary CP require-

Table 3. Comparison of factorial and metabolizable protein systems for calculation of protein requirements of finishing beef cattle

System ^a	
Factorial	Metabolizable
Factorial losses	Animal requirements
Metabolic fecal N = 33.44 g/kg of DMI = 308.92 g	MP for maintenance = $3.8 \times \text{BW}^{.75} = 358.92 \text{ g}$
Endogenous urinary N = $2.75 \times \text{BW}^{.5} = 57.04 \text{ g}$	Net protein in gain = shrunk BW gain $\times (268 - 29.4 \times (\text{retained energy/shrunk BW gain}))$, where retained energy = 7.97 Mcal = 200.94 g
Scurf losses = $.2 \times \text{BW}^{.6} = 7.61 \text{ g}$	MP for gain = net protein in gain/.492 = 408.42 g ^b
Net protein in gain = shrunk BW gain $\times (268 - 29.4 \times \text{energy content of gain})$, where energy content of gain = 4.88 Mcal/kg = 202.15 g	Total MP need = MP for maintenance + MP for gain = 767.34 g
Total of factors = 575.71 g	Microbial synthesis
Dietary requirements	Microbial CP synthesis = $.13 \times \text{g of TDN intake} \times (1 - (20 - \text{effective NDF}) \times .022) = 839.87 \text{ g}$
Dietary CP need = $575.71 \text{ g}/(.9 \times .66)$, where .9 is the true digestibility of protein and .66 is the biological value of absorbed amino acids = 969.22 g	Supply of dietary requirements
Dietary CP, % needed = $969.22 \text{ g}/9.24 \text{ kg of DMI} = 10.49\%$	Microbial MP supplied = Microbial CP $\times .64 = 537.52 \text{ g}$
Intact CP needed = $2 \times \text{CP} - 8.89 - (74.62 \times \text{NE}_m - 70.04 - 14.13 \times \text{NE}_m^2)^{.5} = 7.08\%$	MP needed from UIP = Total MP need - Microbial MP supplied = 229.82 g
Nonprotein N = CP - intact CP = 3.41%	CP needed from UIP = MP needed from UIP/.8 = 287.28 g
Urea use = $3.41/2.87 = 1.19\%$ of DM	Dietary CP need = CP needed from UIP + CP needed for microbial CP synthesis = 1,127.15 g
	Dietary CP, % = $1,127.15 \text{ g}/9.24 \text{ kg of DMI} = 12.2\%$
	DIP and UIP balance
	DIP supply = 608.14 g
	DIP deficit = $839.87 \text{ g of microbial CP} - 608.14 \text{ g} = 231.73 \text{ g}$ or 80.7 g of urea (.87% of dietary DM)
	UIP supply = 428.96 g
	UIP surplus = UIP supply - UIP need = 141.68 g

^aFactorial = NRC (1984) and Metabolizable = NRC (1996). MP = metabolizable protein; DIP = degraded intake protein; UIP = undegraded intake protein. See Table 2 for evaluation data.

^bEfficiency of conversion of MP to net protein in gain = .83 - (frame equivalent empty BW $\times .00114$) for frame equivalent empty BW $\geq 150 \text{ kg}$ to $\leq 300 \text{ kg}$; otherwise, efficiency = .492.

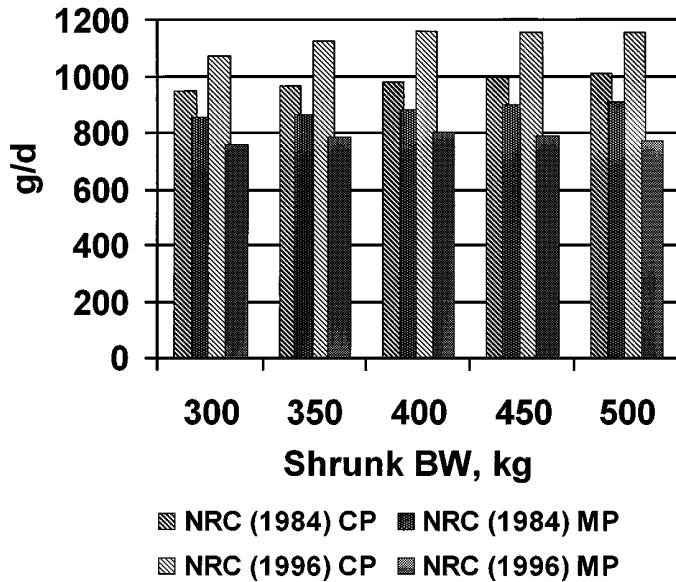


Figure 1. Comparison of the crude protein (CP) and metabolizable protein (MP) requirements (grams/day) of a large-framed steer calf or compensating medium-framed yearling steer at various BW calculated with the NRC (1984) factorial system and the NRC (1996) metabolizable protein system. The diet was assumed to be 91% concentrate ($NE_m = 2.15$ and $NE_g = 1.47$ Mcal/kg of DM). For the NRC (1984) system, DMI was predicted from dietary NE_m concentration using the NRC (1984) intake prediction equation, and energy-allowable gain was calculated. For the NRC (1996) system, DMI was adjusted to allow equal energy-allowable gain for the two systems. Requirements for MP in the NRC (1984) system were calculated as the sum of all factors divided by .66.

ments. Microbial MP supply is calculated as 64% of bacterial CP synthesis. Hence, for the data from Table 2, microbial MP supplied all but 229.82 g of the total MP need of the animal (767.34 g of MP needed minus 537.52 g supplied by microbial MP). Total dietary CP needed is the sum of microbial needs (839.87 g) and CP needed from undegraded intake protein (UIP; MP needed from UIP divided by .8 = 287.28 g), or for this example, a total CP need of 1,127.15 g/d. Based on a DMI of 9.24 kg/d, the percentage of CP needed to meet the protein requirements would be 12.2%. This quantity (and percentage) of CP needed assumes that DIP and UIP are balanced, which is not the case in this example. For high-grain finishing diets, DIP values are typically less than needed because of relatively high UIP from grains. Hence, the DIP supply from the diet in this example is only 608.14 g/d, leaving a DIP deficit of 231.73 g. If this deficit is derived from urea, the diet would need to contain .87% urea (231.73 g/2.87 g of CP/g of urea, expressed as a percentage of DMI) on a DM basis. Adjusting for added urea to meet the DIP deficit, the diet in this

example would need to contain approximately 13.7% CP to meet animal needs for MP and microbial needs for DIP, resulting in an oversupply of total CP relative to requirements.

Clearly, the MP system proposed by NRC (1996) yielded estimates of dietary CP requirements that agree more closely with current industry practices than values derived from the NRC (1984) factorial approach. From a calculation standpoint, the difference between results with the MP system and the factorial approach reflects primarily consideration of microbial needs for DIP in the MP system. Given the trend in recent university research for responses to increased levels of CP from degraded sources, there may be a sound biological basis for considering greater microbial needs for DIP with highly fermented finishing diets.

Despite the better "fit" with industry conditions, several questions need to be addressed with regard to the NRC (1996) MP system. Requirements for protein change with BW; however, the example in Table 3 is based on the average BW for a feeding period. Figure 1 illustrates the MP and CP requirements for a large-framed steer calf (or medium-framed compensating yearling) at various BW. For this figure, the diet was assumed to be the same one described in Table 2. The DMI at each BW was predicted from the dietary NE_m concentration (NRC, 1984), and MP and CP requirements (grams/day) were calculated with the factorial method (NRC, 1984). The MP requirements were calculated as the sum of all factors divided by .66. For the NRC (1996) calculations, DMI was adjusted to provide energy-allowable gain equal to that predicted from NRC (1984). The data in Figure 1 illustrate that the total CP required at each BW was greater for NRC (1996) than for NRC (1984) calculations. This increase in total CP needed was not a function of increased requirements for MP; MP needs were less at each BW with NRC (1996) than with NRC (1984) calculations. As noted previously, the increased CP needed with the NRC (1996) approach is primarily a function of the DIP needed for microbial CP synthesis.

Careful evaluation of the DIP component of the NRC (1996) MP system is necessary given the role of DIP in potentially influencing protein requirements calculated with this system. The conversion efficiency of TDN to microbial CP is not likely a constant 13% of TDN intake, as NRC (1996) assumes. This fact is evident by the inclusion of a correction to the efficiency value for diets with less than 20% effective NDF (NRC, 1996). For the example in Table 3, lowering the microbial efficiency value from 13 to 11% decreases the total CP required from 1,127.15 g/d to 1,101.3 g/d, whereas increasing the efficiency to 15% increases CP required to 1,153 g/d (effective NDF correction applied in all three cases). Again, for the example in Table 3, each two percentage unit increase or decrease in efficiency of microbial CP synthesis

raises or lowers the dietary CP level by approximately .3%. The extent to which the DIP requirement must be met fully is largely unknown. Can N recycling partially compensate for a dietary deficit of DIP, particularly in situations in which DIP is deficient but UIP is in excess, as is the case for the example in Table 3? Additional research will be needed to provide quantitative answers to these and other likely questions regarding the NRC (1996) MP system.

Possible Benefits of Additional Protein and(or) Urea

General. The use of CP levels by the feedlot industry that are greater than those suggested by the NRC (1984) factorial method is likely the result of various factors. Potential biological factors will be discussed in subsequent sections. However, several practical management factors also may affect dietary CP levels used by the industry. Commercial feedlots typically feed cattle in pens of 100 or more animals, with considerable within-pen variation in BW and frame size. Lighter and(or) large-framed cattle in such pens may need more protein; hence, increasing dietary CP level may improve overall performance by a pen. Variation in feed milling and delivery also might affect CP levels. Formulating for higher CP levels than suggested by NRC (1984) calculations may provide a safety factor to offset day-to-day variations in milling and delivery. Management factors that decrease DMI (e.g., extensive grain processing and certain ionophores) could necessitate formulating a greater percentage of CP, even though CP requirements (grams/day) of animals may be unchanged. The extent to which these factors have contributed to formulation practices of the feedlot industry is unknown, but they should not be overlooked with respect to their potential importance in evaluating current industry conditions.

Effects of Implant Programs. The recent university research reviewed previously suggests that aggressive implant programs, particularly those based on combinations of estrogenic and androgenic (trenbolone acetate) compounds, increase daily protein accretion. Such effects would be particularly evident during the initial phase of the finishing period when protein accretion is rapid, which coincides with the initial release phase of the implant. Increased DMI, and thereby CP intake, with implants might, in part, offset potentially increased protein needs. Effects of higher dietary CP levels in aggressively implanted cattle might diminish with time on feed, perhaps being more important with compensating yearling cattle and during the initial phase of the finishing period of large-framed calves. Dietary CP levels can be decreased during the latter stages of the feeding period with aggressively implanted cattle without

markedly affecting performance (see Trenkle, 1995a), but decreasing the CP level below 10% seems inappropriate (see Bartle and Preston, 1994).

Microbial Response to Ruminally Degraded Nitrogen. As noted previously, many of the university research trials suggest maximum performance benefits from supplemental CP sources that may be extensively degraded in the rumen (e.g., soybean meal, urea, or soybean meal:urea combinations). Highly processed grain diets, which provide large quantities of fermentable OM, might increase the microbial need for DIP. With DIP limiting, total energy yield from fermentation and ultimately cattle performance might be affected. Hence, increased ruminal and total tract starch digestion were noted by Milton and Brandt (1994c) and Zinn (1995) with incremental additions of urea to high-grain finishing diets. Limitations in DIP supply to the microbes would seem to be most critical with diets based on highly processed diets (e.g., steam flaking) typical of those currently used by the Great Plains feedlot industry. High-moisture corn, a readily fermented grain, is a likely exception to this generalization. Most consultants surveyed for this review gave consideration to DIP supplied by feed ingredients, particularly high-moisture corn. As noted previously, Secrist et al. (1995) reported potentially adverse effects of dietary CP levels in excess of 12% with high-moisture corn diets.

Assuming that certain highly fermented diets limit DIP supply to microbes, the MP system of NRC (1996) would be expected to more accurately predict protein requirements with such diets than the NRC (1984) factorial approach, which does not account directly for microbial needs. If one assumes that the typical ratio of microbial N synthesized to OM truly fermented in the rumen is 25 g/kg with highly processed finishing diets (see Zinn, 1995), and that the N must be supplied all in the form of DIP, with a 60% true ruminal OM digestibility, dietary CP from DIP would need to be approximately 9.4%. This value compares with 9.1% dietary DIP in the MP system calculations considered in Table 3.

Buffering Effects of Urea and(or) Degradable Nitrogen. Hydrolysis of urea to CO₂ and NH₃ in the rumen could lead to potential buffering effects via ammonia, which in turn could moderate ruminal and systemic acid loads. Perhaps the increased feed intake noted in some experiments with increasing degraded N supplementation (see Shain et al., 1994; Healy et al., 1995; and Zinn, 1995) reflects such a decrease in acid load. Nonetheless, direct measurements of the effects of urea and(or) degradable N supplementation on ruminal pH are limited. Zinn (1995) noted increased ruminal pH at 1 h after feeding (linear and cubic effects) with more urea added (0, .4, .8, and 1.2% of DM) to steam-flaked barley diets, but effects of high urea levels on ruminal pH were minimal at subsequent times after feeding. Borger et al. (1994)

abruptly switched steers from a corn silage diet to all-concentrate diets with various CP levels (8.3, 10.6, 12.7, and 14.3%; source of supplemental CP not specified) and monitored ruminal pH for up to 174 h after the switch. By 54 h of feeding the all-concentrate diets and up to 168 h, increasing dietary CP to 14.3% increased ruminal pH compared with the 8.3 and 10.6% CP diets; ruminal pH values with the 12.7% CP diet tended to be intermediate. Potential effects of CP concentration in finishing diets on ruminal acid-base balance may be an important aspect of ruminant N metabolism.

Systemic Buffering Effects of Supplemental Nitrogen.

Urine is typically alkaline for roughage-fed ruminants, but with high-concentrate diets, urinary pH becomes more acidic and the ammonium ion becomes the primary carrier of H⁺ in the urine (Erdman et al., 1982). Under conditions of acid stress, excretion of ammonium ion allows for continued H⁺ excretion and maintenance of acid-base balance (Pitts, 1974). Glutamine, the principal source of ammonia for the kidney (Pitts, 1974), is produced largely from transamination reactions.

The quantitative role of supplemental CP in providing a supply of both amino acids and ammonia for systemic buffering in ruminants fed high-concentrate diets is unknown. Clearly, consumption of highly fermented, grain-based diets would result in a substantial acid load, thereby increasing the likelihood that ammonium ion excretion becomes an increasingly important component of the buffering system of the kidney. Might supplying additional DIP increase ammonia and/or amino acid flow to the small intestine and thereby increase precursors for ammonium ion excretion and maintenance of acid-base balance? Perhaps, as with potential ruminal buffering effects of DIP, increased DMI noted with supplemental DIP in many research trials might be related to systemic buffering of a chronic acid load. This is one area of ruminant N metabolism that may be important with high-concentrate diets.

Research Needs

Diet formulation and management changes in the feedlot industry have stimulated research efforts in the academic community, but several questions remain to be answered. Effects of aggressive implant programs on protein needs have received the most attention, but further efforts to define more clearly the optimum sources of supplemental CP and the potential effects of protein on carcass quality are needed. Degraded N supply may be limited with many highly processed grain diets, but few experiments are available that provide estimates of microbial growth and site and extent of nutrient digestion with diets typical of those used by the feedlot industry and, perhaps more

critically, with feed intakes that approximate industry conditions. Attaining production levels of feed intake in metabolism experiments may not be an obtainable goal, but it should be the goal. Additional studies are needed on potential metabolic and hormonal effects of dietary protein. For example, pancreatic α -amylase secretion and intestinal starch digestion may respond to increasing duodenal protein flow (Huntington, 1995) and protein quality (Castlebury and Preston, 1993), and, as noted previously, supplemental CP may play a role in systemic acid-base balance. Given environmental concerns, research efforts also should focus on determining feeding standards for protein that are compatible with minimizing N waste. Finally, more effort needs to be made by the academic community to conduct cooperative research with the feedlot industry. Large computer databases on cattle performance are available in the industry for analysis of general trends. Moreover, many segments of the feedlot industry are increasing "in-house" research efforts and likely would cooperate with the academic community. Working in step, the academic community and the feedlot industry no doubt can answer many of the current questions related to protein nutrition of feedlot cattle.

Implications

The typical percentage of crude protein in beef cattle finishing diets in current use by the feedlot industry exceeds 12% of dietary dry matter, which is considerably greater than would be predicted from the factorial system for calculating protein requirements. A metabolizable protein system yielded estimates of crude protein requirements that agreed more closely with current fortification levels, presumably because the metabolizable protein system accounted for microbial nitrogen needs. Current university research results suggest that protein needs of finishing beef cattle may be increased by implant programs that involve the use of estrogen plus trenbolone acetate, at least in the early part of the feeding period. Responses to supplemental protein often are greater with ruminally degraded vs undegraded sources. Research is needed to investigate factors that may be responsible for production responses to supplemental protein, including alleviation of a microbial nitrogen deficiency and alterations in ruminal and systemic acid-base balance.

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