Feeding Protein to Dairy Cows – What Should Be Our Target?

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Abstract

Dietary protein is the most important factor determining milk N efficiency, urinary N losses, and consequently, ammonia emissions from dairy cow manure. Based on long-term trials conducted at Penn State, we conclude that dairy cows producing up to 88 lb/day can be safely fed balanced diets with 16% (and even 15%) crude protein **(CP)** without affecting milk production or composition. Diets with CP <15% [metabolizable protein **(MP)** deficiency of <-12%] will likely result in decreased milk yield, partially through decreased dry matter intake **(DMI)**. Cows fed low-CP diets (i.e., MP-deficient) may benefit from supplementation with rumen-protected amino acids **(AA)** that limit production (again, partially through an effect on DMI). Our data demonstrated that histidine **(His)** is a limiting AA in MP-deficient, corn silage/alfalfa haylage-based diets, and long-term trials showed that supplementation of the diet with rumen-protected His increased or tended to increase milk yield and milk protein percent and yield, mainly through increasing DMI. Total tract fiber digestibility will likely be decreased with CP < 16% (rumen-degraded protein ≤ 10% of DM) in diets.

Introduction

The multifaceted role of dietary protein in the nutrition of the dairy cow and overall farm sustainability can be summarized as: (1) effects on DMI, milk yield, and milk composition, (2) effects on feed costs, (3) environmental effects, and (4) possible effects on reproduction efficiency. The role of nitrogen **(N)** emitted from livestock operations in water and air pollution has been known for decades (Viets, 1974). Nitrogen, along with phosphorus, is a major cause of water quality impairment (USEPA, 2009). In addition to the environmental issues, ammonia-N volatilization is a net loss of manure fertilizer value to the producer. For example, daily ammonia-N losses of 25 to 50% of the N excreted in manure have been estimated using mass balance approaches for dairy cows and feedlot cattle (Hristov et al., 2011). When applied at equal soil N application rates, manure from cows fed a 16.7% CP diet resulted in markedly greater ammonia emissions and leachate nitrate-N losses than manure from cows fed a 14.8% CP diet (Lee et al., 2014).

Nitrogen excreted with animal feces or urine has different fates and contributes differently to ground water nitrate and ammonia emitted from cattle manure. Once excreted in manure, urinary N is more labile that fecal N. Using 15N-labaled urine or feces, Lee et al. (2011a) demonstrated that more than 90% of ammonia-N emitted during the first 10 days of manure storage originated from urine. The fact that urine is the primary contributor to ammonia and total N losses from manure

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emphasizes the importance of reducing urinary N losses and/or shifting N excretion from urine to feces. Meta-analyses have unequivocally shown that reduction in dietary N input can be a successful strategy for improving N utilization efficiency and reducing N losses with manure in dairy cows (Huhtanen and Hristov, 2009; Hristov et al., 2011). Reducing dietary protein can also benefit the producer by reducing feed cost and improving overall farm profitability. There are many examples where decreasing protein concentration in diets for dairy or beef cattle dramatically decreased manure N losses without affecting animal production (Hristov et al., 2011). These interventions, however, have to be balanced with the risk of loss in production. If the animal requirements for MP are not met, long-term production cannot be sustained.

The question is: What is the limit in decreasing MP, after which we start losing production? In some cases, dietary CP as low as 12% (meeting utilizable CP at the duodenum requirements, but at a negative rumen N balance), did not affect milk production in dairy cows, although nutrient digestibility and microbial protein synthesis in the rumen were depressed (Aschemann et al., 2012). In that study, however, cows were relatively low producers (about 63.8 lb/day) and intake was restricted, i.e. the important effect of protein on feed intake (Picard et al., 1993; Lee et al., 2012a) could not be demonstrated. In some trials, in which there were no statistical effects with MP-deficient diets, clear numerical trends for decreased DMI and/or milk production were observed. For example, Olmos Colmenero and Broderick (2006) fed diets varying in CP content from 13.5 to 19.4% (RDP increased from 9.3 to 12.7% and RUP from 4.2 to 6.7%). Dry matter intake and milk yield were not affected statistically in this trial, but the 13.5% CP diet resulted in about 1.5 lb/day DMI ($P > 0.22$) and 4.4 lb/day less milk ($P = 0.10$; a quadratic response) compared with the 16.5% CP diet.

Trials with high-producing dairy cows at Penn State have shown a variable (in most cases not statistically significant) effect of dietary CP or MP-deficiency on DMI. In trials where DMI was decreased (statistically or numerically) with the MP-deficient diets, milk production also decreased (Lee et al., 2011b; Lee et al., 2012a). On the contrary, when DMI did not decrease, milk production also was not different from the control, MP-adequate diets (Lee et al., 2012b; Giallongo et al., 2014). In all trials, total tract apparent NDF digestibility was decreased (6 to 20%) by the low-CP, MP-deficient diets. Interestingly, this did not affect milk production or milk fat content (although numerical trends were observed in some cases; Lee et al., 2012b). Thus, it appears production losses with low-protein diets are caused by: (1) depressed DMI due to impaired rumen function or physiological regulation of intake, (2) deficiency of ruminally-degradable protein **(RDP)**, which may cause decreased fiber digestion, and (3) insufficient supply of key AA limiting milk protein synthesis. We are emphasizing that the effect of low-protein diets on feed intake is critical and must always be considered (Lee et al., 2012a). For example, an analysis of the literature from a few years ago (31 studies in the Journal of Dairy Science, volumes 78 to 91; 1995 to March 2008; Huhtanen and Hristov, 2009), in which CP level in the diet was a main effect, showed increased milk protein yield (MPY) with increasing dietary CP in 7 experiments. In 5 of these 7 experiments, however, the effect on MPY was through increased DMI. In only 2 trials was MPY significantly increased with increasing dietary CP concentration, whereas there was no significant effect on DMI.

Strategies for Feeding Low-protein Diets

The Dairy NRC (2001) model predicts that a diet, based on corn silage and alfalfa hay, steam-flaked corn grain, soybean meal **(SBM)**, whole cottonseed, and 0.5% (DM basis) blood meal with about 16% CP and at 55 lb/day DMI meets the MP requirements (and exceed the NE_L requirements) of a 1500 lb/90-days-in-milk cow with milk production of 88 lb/day and 3% true milk protein (Table 1). Similarly, a diet based on corn silage, alfalfa haylage, grass hay, whole roasted soybeans, canola meal, and about 6% by-pass SBM containing 16% CP met the MP requirements of cows at similar level of production in our experiments at Penn State. The RDP balance for this diet was on average 3 g/day. If this diet was formulated at 17% CP, by replacing the hay with haylage and including some solvent-extracted SBM (partially replacing the by-pass SBM), the MP requirements would still be met but the RDP balance would be 286 g/day. As demonstrated in a number of experiments, RDP excess will increase urinary N and urea losses and consequently, ammonia emissions from manure (van Duinkerken et al., 2005; Agle et al., 2010). In the study by Olmos Colmenero and Broderick (2006), for example, urinary urea N excretion more than tripled with increasing the CP content of the diets from 13.5 to 19.4%. Decreasing RDP balance to about -200 g/day resulted in a 40% decrease in the ammonia-emitting potential of manure in the study by Lee et al. (2012b).

Long-term (up to 10 wks), continuous design trials conducted with cows producing 83.6 to 94.6 lb/day of milk at Penn State showed that decreasing NRC (2001)-estimated MP supply to 8 to 13% below requirements may result in depressed DMI and/or decreased milk production. These diets were usually around 14% CP. In one study (Lee et al., 2012b), diets supplemented with rumen-protected **(RP)** AA that were 12 to 13% deficient in MP (14% CP) did not result in decreased production. In a recent trial with cows milking around 94.6 to 99 lb/day, 5 to 8%-MP deficient diets also did not result in depressed DMI or milk production (Giallongo et al., 2014). It may be important to point out that in these trials, the calculated MP balance was based on the actual DMI and production of the cows. One could debate the correct way of estimating MP requirements – based on actual or potential milk production and composition (i.e., the production of the positive control group, assuming all cows on trial have equal production potential). In some cases, this could make a difference, although in the Penn State trials, we found it of little relevance (i.e., the effect on MP requirements was small and inconsequential).

The first and most important factor for successful reduction of dietary protein close to or below the animal's MP requirements is to keep dietary energy balance at or in excess of requirements. Amino acids are inevitably used for glucose synthesis by the cow, but their role as a source of energy to sustain production becomes more important if dietary energy is deficient. In our experience, diets with CP of around 14% are RDP-deficient, which is manifested in decreased total tract NDF digestibility. Although we have not measured ruminal fiber degradability, it is safe to assume that a big part, if not all, of the decrease in total tract fiber digestibility occurred in the rumen. We were not able to detect, at least with the indirect method we used, a consistent response in microbial protein syntheses in the rumen with the low-CP diets. Overall, our data indicate that diets with RDP of around 9 to 10% (of dietary DM) decrease fiber digestibility, but do not appear to have a consistent effect on ruminal microbial protein synthesis.

In our trials with MP-deficient diets, the NRC (2001) protein model underpredicted milk response by about 5 lb per 100 g MP deficiency (Lee et al., 2012b). Similar trends were reported by Lee et al. (2012a); on average, underprediction of milk yield in the MP-deficient groups of cows was 22.7 ± 1.7 lb/day. In a more recent trial with 60 cows, in which DMI was not affected by the MP-deficient diets, milk yield was underpredicted by NRC (2001) on average by 7.7 ± 1.5 lb/day (Giallongo et al., 2014). Possible reasons for these effects may include overestimation of RDP requirements, urea recycling, and variable efficiency of conversion of MP for metabolic functions (see discussions in Doepel et al., 2004 and Huhtanen and Hristov, 2009).

Diets with CP concentration of around or below 16% are not uncommon on commercial dairy farms in the Northeast. In our on-farm projects (unpublished data from Hristov et al., 2012 and Weeks et al., 2014) total mixed rations **(TMR)** from dairy farms that ranged from 60 to 80 lb/day of milk often analyzed below 16 and in some cases below 15 and even 14% CP. With the understanding of possible unrepresentative sampling and other factors that could affect diet composition (TMR mixing, for example), it is apparent to us that on commercial farms, and particularly when feed prices are high, diets may reach critically low levels of CP that may limit production in some herds.

Supplementation with RPAA that limit milk production and milk protein synthesis may compensate for MP deficiency in dairy cow diets. In some cases, this was a successful strategy to maintain production (Leonardi et al., 2003; Berthiaume et al., 2006; Broderick et al., 2008), but not in others (Socha et al., 2005; Davidson et al., 2008; Benefield et al., 2009). Amino acid supplementation research at Penn State has pointed to His as a limiting AA in dairy cows fed typical North American diets – based on corn silage, alfalfa haylage, corn grain, and soybean or canola meals. Lee et al. (2012a) reported a trend for increased DMI when RPHis was added to a 13% MP-deficient diet supplemented with RPLys and RPMet. The increased DMI triggered milk and milk protein yield responses. Analysis of rumen bacterial samples from various trials conducted at Penn State indicated about 27% lower His than Met concentration in bacterial protein. Microbial protein is an increasingly important source of AA for the cow when MP-deficient diets are fed, and we proposed that His may be a limiting AA in high-producing dairy cows fed corn silage- and alfalfa haylage-based diets deficient in MP. Our analysis indicated that the proportion of His in MP should be similar to that of Met, which for practical purposes, is suggested to be 2.2%. Others have suggested His requirements of 2.4 (Doepel et al., 2004), 2.3 (Lapierre et al., 2014), and up to 3.4% (Rulquin and Pisulewski, 2000) of MP.

Our hypothesis that His is a limiting AA in North American dairy cows was based on data from Europe with grass silage-based diets (Kim et al., 1999; Vanhatalo et al., 1999) and the consistently lower blood plasma His concentrations in long-term trials with MP-deficient diets conducted at Penn State (Lee et al., 2012a,b). We have to emphasize the importance of experimental design in trials in which production effects are investigated. In contrast to data from long-term experiments (Lee et al., 2012a,b), plasma His concentrations were not different in cows fed MP-adequate or MP-deficient diets in a parallel Latin square design trial with 21-day experimental periods (Lee et al., 2011c). As discussed by Lapierre et al. (2008), His may be unique among the essential AA by having labile pools that provide a source of stored His during short periods of deficiency (i.e., intramuscular carnosine and anserine, dipeptides containing His, and circulating hemoglobin). Carnosine along with hemoglobin as sources of His have been discussed in human nutrition (Rose et al., 1951; Irwin and Hegsted, 1971) and the mechanism was observed in rats by Nasset and Gatewood (1954) who reported negative N balance and a decrease in blood hemoglobin when His was omitted from the diet. In dairy cows, the carnosine/hemoglobin mechanism may be sufficient to maintain His supplies in short, Latin square, or crossover experimental periods.

We have recently conducted a 10-wk randomized complete block design trial with 60 cows (87 ± 40 DIM) with the main objective of investigating the effects of slow-release urea and RPMet and RPHis supplementation of a MP-deficient diet on lactation performance (Giallongo et al., 2014). By inclusion of slow-release urea in the diet, we were hoping to address the lower NDF digestibility observed with MP-deficient diets in our trials. This trial had 5 dietary treatments: MP-adequate diet **(AMP)**; MP-deficient diet **(DMP)**; DMP supplemented with Optigen (Alltech Inc.; DMPO); DMPO supplemented with RPMet as Mepron (Evonik Industries AG; DMPOM); and DMPOM supplemented with RPHis (Balchem Corp.; DMPOMH). The basal diet consisted of (DM basis): 43% corn silage, 8% grass hay, 4% cottonseed hulls, and 45% concentrate and contained 16.7, 15.8, and 14.8% CP for AMP, DMPO, and DMP, respectively. The MP balance (based on NRC, 2001) was: 206 (about 107% of the requirements), -145 (about 95% of the requirements), -244, -116, and -164 g/day, respectively. All diets were deficient in Lys [from -10 to -28 g digestible (d)Lys/day; requirements were assumed at 6.6% of MP]. The diets that were not supplemented with RPAA were also deficient in Met (from -13 to -17 g dMet/day; requirements were assumed at 2.2% of MP). The DMP, DMPO, and DMPOM diets were -5 to -8 g/day deficient in dHis (based on dHis requirements of 2.2% of MP), with both the AMP and DMPOMH diets meeting or exceeding dHis requirements. Similar to previous trials, total-tract apparent digestibility of all nutrients and urinary N and urea excretions were decreased by DMP compared with AMP. Milk N efficiency (milk true protein N secretion as a proportion of N intake) tended to be higher (P = 0.07) for the MP-deficient diets. The production data from this trial are shown in Table 2. Dry matter intake was not affected by MP level but tended to be higher for the RPHis-supplemented diet compared with the RPMet-supplemented diet. Yields of milk and milk fat were not affected by treatment; there was a trend for decreased milk fat percentage with the RPHis-supplemented diet. Milk true protein content was increased and milk protein yield was numerically increased by RPHis addition to the RPMet-supplemented diet. Cows fed DMP gained 14 g/day BW, whereas cows on all other treatments gained on average 267 g/day. This important observation, which was unlikely to be observed in a short-term trial, suggested that cow on the DMP diet were not gaining BW, whereas cows on the supplemented diets (with slow-release urea or RPAA) were recovering BW lost in early lactation. The conclusion from this trial was that feeding a 5% MP-deficient diet did not decrease DMI and yields of milk and milk components, despite the reduction in nutrient digestibility. Supplementation with RPHis tended to increase DMI and increased milk protein content. These results confirmed our previous data and suggest that His may have a positive effect on voluntary feed intake in high-yielding dairy cows. We were not able to show a positive effect of slow-release urea on total tract fiber digestibility.

Conclusions

Dietary protein is the most important factor determining milk N efficiency, urinary N losses, and consequently, ammonia emissions from dairy cow manure. Dairy cows producing up to 88 lb/day can be safely fed balanced diets with 16% (and even 15%) CP without affecting milk production or composition. Diets with CP <15% (MP deficiency of <-12%) will likely result in decreased milk yield, partially through decreased DMI. Low-CP diets (i.e., deficient in MP) may benefit from supplementation with rumen-protected AA that limit production (again, partially through an effect on DMI). Our data demonstrated that His is a limiting AA in MP-deficient, corn silage/alfalfa haylage-based diets, and long-term trials showed that supplementation of these diets with rumen-protected His increased or tended to increase milk yield and milk protein percent and yield, mainly through increasing DMI. Total tract digestibility of NDF will likely be decreased with diets with CP < 16% (RDP ≤ 10% of DM).

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Table 1. Example NRC (2001) diets that meet the metabolizable protein (MP) requirements of a 1500 lb/90-days-in-milk cow with milk production of 88 lbs/day and 3% true milk protein, consuming 55 lb/day DMI.[1]

	NRC (2001) sample 90 DIM lactating cow diet	NRC (2001) diet formulated at 16% CP	NRC (2001) formulated at 17% CP
Crude protein, %	16.0	15.9	17.0
Rumen-degraded protein, % CP	10.0	9.8	10.9
Rumen-undegraded protein, % CP	6.0	6.2	6.1
Rumen-degraded protein supply, g/day	2,471	2,445	2,731
Rumen-degraded protein balance, g/day	-28	3	286
Rumen-undegraded protein supply, g/day	1,484	1,539	1,525
Rumen-undegraded protein balance, g/day	52	12	10
MP supply, g/day	2,706	2,716	2,714
MP balance, g/day	44	10	8
NE_L balance, Mcal/day	1.9	0.9	1.2

[1]DMI = Dry matter intake, CP = crude protein, MP = metabolizable protein, and NE_L = net energy for lactation.

Table 2. Effects of slow-release urea and rumen-protected amino acid supplementation on dry matter intake (DMI), milk production and composition, and body weight (BW) change in dairy cows (covariate-adjusted means)[1].

	Diet[2]						Contrasts[3]				
Item	AMP	DMP	DMPO	DMPOM	DMPOMH	SEM	CP	O	Met	His	AA
DMI, lb/day	60.7	59.6	59.2	59.4	62.5	1.3	0.51	0.76	0.89	0.09	0.24
Milk yield, lb/day	96.6	96.6	95.3	96.4	99.7	2.4	1.00	0.68	0.74	0.32	0.33
Milk yield/DMI, lb/lb	1.62	1.63	1.63	1.66	1.60	0.039	0.80	0.95	0.58	0.31	0.96
BW, lb	1437	1417	1430	1437	1448	10.0	0.11	0.27	0.61	0.42	0.29
BW change, lb/day[4]	0.64	0.03	0.48	0.74	0.0002	0.1	0.02	0.10	0.98	0.34	0.55
Milk fat, %	3.52	3.56	3.55	3.78	3.36	0.180	0.87	0.96	0.29	0.06	0.90
Milk protein, %	3.18	3.15	3.21	3.16	3.26	0.033	0.44	0.20	0.31	0.04	0.97
Milk fat, lb/day	3.48	3.28	3.43	3.63	3.39	0.20	0.47	0.58	0.44	0.34	0.71
Milk protein, lb/day	3.10	2.93	3.10	3.06	3.28	0.10	0.24	0.22	0.77	0.14	0.60
4% FCM, lb/day[5]	92.0	86.5	90.4	93.5	91.3	4.1	0.31	0.46	0.56	0.67	0.66

[1]Data from Giallongo et al. (2014).

[2]AMP = MP-adequate diet; DMP = MP-deficient diet; DMPO = DMP diet supplemented with Optigen (Alltech Inc., Nicholasville, KY); DMPOM = DMP diet supplemented with Optigen and RPMet (Mepron; Evonik Industries AG, Hanau, Germany); and DMPOMH = DMP diet supplemented with Optigen, RPMet, and RPHis (Balchem Corp., New Hampton, NY).

[3]CP = MP-adequate diet (AMP) versus MP-deficient diet (DMP); O = DMP versus DMPO; Met = DMPO versus DMPOM; His = DMPOM versus DMPOMH; and AA = DMPO versus DMPOM and DMPOMH.

[4]BW change, g/day = [(Average BW, final week of trial – Average BW, 2nd week of covariate period) ÷ days on trial (around 70 days for most cows)].

[5]Fat-corrected milk.