

The Principles of Balancing Diets for Amino Acids and Their Impact on N Utilization Efficiency

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Introduction

Progress continues to be made in balancing lactating dairy cow rations for amino acids (**AA**). Commercial sales of rumen protected methionine (**Met**) supplements continue to increase and numerous rumen-protected lysine (**Lys**) supplements and additional high-Lys blood-based products have been introduced within the last couple of years, all designed to make it easier to meet Lys and Met requirements without oversupplying the other AA. Dairy nutritionists are also becoming more comfortable in more precise balancing of rations for rumen degradable protein (**RDP**) and rumen undegradable protein (**RUP**) and lowering RUP feeding as AA balancing allows. Available evidence indicates that implementing approaches to better target the needs of rumen fermentation and the AA requirements of the cow are equally important in balancing diets for AA. Advances in nutrition research, feed analysis, high quality protein and AA supplements and ration formulation models have set the stage, but it's been the passion of dairy nutritionists who want to better meet the needs and desires of their producers, and the health and profitability of their cows, that are behind the success that has been, and will likely continue to be, achieved.

The purpose of this paper is to review current knowledge regarding limiting AA and their optimum concentrations in metabolizable protein (**MP**), feeding strategies to better match AA supply with AA requirements with a less than complete knowledge of requirements and less than perfect nutrition models, and to review two selected studies that highlight the importance of balancing diets for Lys and Met on efficiency of N utilization. The hope is to assure those that are not balancing rations for Lys and Met, or not doing so correctly, that existing knowledge and models are more than adequate to take the first step. The benefits to the producer and their cows are often too large to do otherwise, particularly if there is an interest in optimizing dairy herd health and profitability.

Amino Acids – The Required Nutrients

It has been known for decades that animals require AA for the synthesis of tissue, regulatory, protective and secretory proteins and that there are hundreds of these proteins that must be synthesized every day. It is also well documented that the AA composition of each protein is different, that protein synthesis is a genetically

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determined event, and that as a result, the AA composition of a protein is the same every time it is synthesized. Besides their role in protein synthesis, which affects virtually every aspect of metabolism in every living cell, AA are also key regulators of various pathological and physiological processes, including immune responses, as well as being used for the synthesis of all of the other N-containing compounds in the body, which includes dozens of compounds such as hormones, neurotransmitters, nucleotides (RNA and DNA), histamine, polyamines such as spermine and spermidine, etc. These observations are mentioned to highlight the impact that AA have on overall body metabolism and the likely importance that optimizing AA nutrition has on health, fertility and production performance of animals. Finally, for nearly as long as the nutritive significance of AA has been recognized, it has been known that some of the AA cannot be synthesized by the animal, or synthesized fast enough, from other AA, to meet requirements for protein synthesis. These AA were termed essential AA (**EAA**) (Rose, 1938). The remaining AA that are needed for protein synthesis but can be synthesized by the animal were called nonessential AA.

Importance of Amino Acid Balance

What this early understanding of AA nutrition and subsequent research has indicated is that: 1) AA are the building blocks for protein synthesis, 2) the ideal profile of absorbed EAA may be different for maintenance, growth, pregnancy and milk production and that as a result, the ideal profile may be different for an animal at different stages of its life cycle or at different physiological states (e.g., high vs. low milk production), and that 3) providing a more balanced profile of absorbable EAA allows meeting AA requirements with less dietary protein. The latter point has been exploited by the swine and poultry industry. By selective use of protein supplements and feed grade sources of the most limiting AA such as Lys and Met, AA requirements are being met with lower concentrations of dietary protein.

Balancing diets for AA also has the advantage of sparing dietary protein for dairy cows, but the protein fraction that is spared is RUP, not RDP. Balancing diets for AA provides the opportunity to supply similar or greater amounts of the most limiting AA with reduced or similar concentrations of RUP. However, because microbial protein provides about 50% of the absorbed AA requirements of lactating dairy cows, there is less opportunity to spare as much as RUP in cows as total dietary protein in pigs or chickens.

Limiting Amino Acids

Lysine and Met have been identified most frequently as the two most limiting AA for lactating dairy cows in North America (NRC, 2001). A variety of research studies continue to support these early observations (e.g., Appuhamy et al., 2011, Chen et al., 2011; Doepel and Lapierre, 2010, 2011; Noftsgger and St-Pierre, 2003; Noftsgger et al., 2005; Ordway et al., 2009; Socha et al., 2005; St-Pierre and Sylvester, 2005). That Lys and Met are the first two limiting AA for lactating dairy cows should not be surprising

given their low concentrations in most feed proteins relative to their concentrations in rumen bacteria or in milk and tissue protein (Table 1).

Many nutritionists have questioned the possibility of histidine (**His**) as a potential limiting AA. However, to the author's knowledge, His has only been identified as first limiting when grass silage and barley and oat diets were fed, with or without feather meal as a sole or primary source of supplemental RUP (Kim et al., 1999, 2000, 2001a, 2001b; Huhtanen et al., 2002; Korhonen et al., 2000; Vanhatalo et al., 1999). None of these diets contained corn or corn byproducts. Based on NRC (2001) predicted concentrations of Lys, Met, and His in MP for the diets fed in these experiments, coupled with similar evaluations of diets where cows have (or have not) responded to increased levels of Lys and Met in MP (McLaughlin, 2002), leads the author to speculate that His may become the third limiting AA in some diets, particularly where no blood meal is being fed and where barley and wheat products replace significant amounts of corn in the diet.

Ideal Balance of Absorbed AA

Attempts to establish initial estimates of the ideal concentrations of EAA in MP are limited. Rulquin et al. (1993) used an indirect nutrient-response approach to establish the concentrations of Lys and Met that are needed in MP to maximize milk protein yield. Experiments were limited to those involving lactating dairy cows fed Lys or Met deficient diets and where one or more amounts of Lys or Met were infused into the abomasum or duodenum, or where one or more amounts of a rumen inert, protected Lys or Met supplement was fed. This approach involves 5 steps: 1) predicting concentrations of Lys and Met in MP for control and treatment groups in experiments in which post-ruminal supplies of Lys, Met, or both were increased and production responses were measured, 2) identifying a "fixed" concentration of both Lys and Met in MP that are intermediate to the lowest and highest values in the greatest number of Lys and Met experiments, 3) calculating, by linear regression, a "reference production value" for each production parameter (in this case, milk protein yield) in each Lys experiment that corresponded to the "fixed" level of Lys in MP and in each Met experiment that corresponded to the "fixed" level of Met in MP, 4) calculating "production responses" (plus and minus values) for control and treatment groups (within each experiment) relative to the "reference production values", and 5) regressing the production responses on the predicted concentrations of Lys and Met in MP. The French PDI System was used to predict AA supply from the basal diets. Based on a limited number of infusion experiments, Rulquin et al. (2001) also proposed requirements for the other EAA. The results of these studies are presented in Table 2.

The NRC (2001) committee also used the indirect nutrient-response approach as described by Rulquin et al. (1993). The intent here was to establish the concentrations of Lys and Met needed in MP to maximize both content and yield of milk protein. In this case, however, the NRC (2001) model was used to predict AA supply from the basal diets. A rectilinear model was used to describe the dose-response relationships with

the breakpoints establishing the required concentrations of Lys and Met in MP (Table 2).

As a follow up to the efforts of NRC (2001), Doepel et al. (2004) constructed a similar database of published experiments, but they limited their experiments to those involving infusions of casein or free AA into the abomasum, duodenum, or blood. Like NRC (2001), the researchers used the NRC (2001) model to predict AA supply from the basal diets. Total milk protein yield was defined as a function of individual AA supply using a segmented-linear model and a logistic model to obtain estimates of the efficiency of conversion of AA into milk protein. The authors reported that except for Lys and Met supply, the segmented-linear model yielded lower root mean square error and better correlation, but both models were similar in their reliability. Their estimations of the ideal profile of AA in MP were similar between the two models (Table 2).

The different approaches described above have provided strikingly similar recommendations for the optimal supplies of Lys and Met in MP! Both models used by Doepel et al. (2004) predicted an optimal amount of Lys in MP of 7.2% and an optimal amount of Met in MP of 2.5%. Moreover, the Lys value agrees with the Lys recommendations of 7.2% of MP by NRC (2001) and 7.3% of protein truly digested in the small intestine (**PDI**) when expressed on an MP basis by Rulquin et al., (1993). In like fashion, the estimate of Doepel et al. (2004) of the optimal supply of Met (2.5% of MP) is similar to the value of 2.4% by NRC (2001) and it matches the 2.5% of PDI suggested by Rulquin et al. (1993).

Recently, Schwab et al. (2009) re-evaluated the Lys and Met dose-response plots using the final version of the NRC (2001) model, rather than the beta version that had been used previously. The same studies were used and all steps as stated in NRC (2001) were repeated. In like fashion, Whitehouse et al. (2009) repeated the same steps, using the same studies as used for NRC (2001), to generate Lys and Met dose-response plots for CPM-Dairy and AMTS.Cattle ration formulation softwares. This was done for both of the CNCPS-based models because of their wide spread use in the dairy industry and out of concern that users of these models may be incorrectly using recommendations generated using the NRC model. Because of the differences in the biology of these models, it has to be assumed that the required concentrations of Lys and Met in MP for maximum concentrations and yields of milk protein may be different for the different models.

The result of the efforts of Schwab et al. (2009) and Whitehouse et al. (2009) are presented in Table 3. As noted, the breakpoint estimates for the required concentrations of Lys and Met in MP for NRC (2001) for maximal content of milk protein were 6.80 and 2.29%, respectively, lower than the original values of 7.24 and 2.38% reported in NRC (2001). The breakpoint estimates for the required concentrations of Lys and Met in MP for maximal yield of milk protein were 7.10 and 2.52%, respectively. These values are also different from the NRC (2001) values of 7.08 and 2.38%. It was concluded from a comparison of the predicted flows of microbial MP and feed MP with the beta and final versions of the two models, along with a re-examination of feed

inputs, that the primary reason for the differences in breakpoint estimates was differences in feed inputs for some of the studies, rather than differences between the beta and final versions of the model.

As expected, differences existed between the results obtained with NRC, CPM-Dairy and AMTS.Cattle (Table 3). This was expected, as models differ in the approach for predicting supplies of AA. These differences in approach lead to differences in predicted supplies of RDP, RUP, MP and MP-AA. The AA prediction model in NRC (2001) is semi-factorial in nature, where some of the parameters are determined by regression. In contrast, CPM-Dairy and AMTS.Cattle use factorial approaches for predicting AA flows to the small intestine (O'Connor et al., 1993). CPM-Dairy (v.3.0.10) uses CNCPSv.5 and AMTS.Cattle (v.2.1.1) uses CNCPS v.6. The latest version of CNCPS has expanded carbohydrate (**CHO**) pools, modified CHO A1-B1 degradation rates, the soluble fractions (e.g., sugar, nonprotein N) flow with the liquid phase instead of the solid phase, and the passage rate equations have been updated. The result of these and other changes have led to reductions in ruminal CHO degradation, higher RUP and lower microbial protein flows, and lower predicted flows of Lys and Met to the small intestine, as compared to CPM-Dairy.

Reasons for Providing Lactating Dairy Cows with Optimum Concentrations of Lys and Met in MP

1. Reduce the risk of cows experiencing a Lys or Met deficiency, or both, and the resulting consequences of reduced protein synthesis on health and fertility, growth and N balance, and milk and milk component production and increase their chances of realizing their genetic potential for milk yield and component concentrations. Current literature is limited on the metabolic effects of specific AA deficiencies in cows, over and beyond the effects on lactation performance, but it seems reasonable to think that the reported effects of Lys and Met deficiencies in pigs and chickens are also true for lactating dairy cows.
2. Take advantage of the opportunity to feed less RUP in herds where RUP is being over-fed because of low concentrations of Met, or Met and Lys, in RUP and MP.
3. Increase efficiency of conversion of RUP and MP to milk protein and minimize wastage of dietary N.
4. Increase income-over-feed-costs and dairy herd profitability.

Balancing Diets for Lys and Met

The following five feeding strategies have been shown to be effective in balancing diets for Lys and Met, allowing producers to realize the benefits expected of balancing diets for AA.

1. Feed a mixture of high quality forages, processed grains, and byproduct feeds that will provide a blend of fermentable carbohydrates and physically effective fiber that maximizes feed intake, milk production, and yield of microbial protein. Microbial protein has an apparent excellent AA composition for lactating dairy cows. The average reported concentrations of Lys and Met in bacterial true protein of 7.9% and 2.6% (Table 1) exceed the optimum concentrations of 7.2-7.3% and 2.4-2.5% that were established by Rulquin et al. (1993), NRC (2001) and Doepel et al. (2004) (Table 2). Other than the concentrations of both Lys and Met in fish meal, the concentration of Lys in blood meal and Met in oats, the concentrations of Lys and Met in rumen bacteria far exceed concentrations in most other feeds.
2. Feed adequate but not excessive levels of RDP to meet rumen bacterial requirements for AA and ammonia. Realizing the benefits of feeding a balanced supply of fermentable carbohydrates on maximizing yields of microbial protein also requires balancing diets for RDP. Rumen degraded feed protein is the second largest requirement for rumen microorganisms. It supplies the microorganisms with peptides, AA, and ammonia that are needed for microbial protein synthesis. The amount of RDP required in the diet is determined by the amount of fermentable carbohydrates in the diet. Diet evaluation models differ in their estimates of RDP in feeds and animal requirements. The NRC (2001) model typically predicts RDP requirements of 10 to 11% of diet DM. Regardless of the model used, it is important to use the predicted requirements ONLY AS A GUIDE and to fine tune according to available research and animal responses. Monitor feed intake, fecal consistency, milk/feed DM and N ratios, milk fat concentrations, and milk urea N (**MUN**) to make the final decision. A common target value for MUN is 10 mg/dL, but values lower than this is not uncommon in high producing cows with more precise feeding.

Don't short-change the cows on RDP...superior carbohydrate balancing can be negated with an inadequate supply of RDP. Underfeeding RDP decreases microbial digestion of carbohydrates, decreases feed intake, decreases synthesis of microbial protein, decreases production of volatile fatty acids (**VFA**), and decreases milk yield. A deficiency of RDP can suppress the ability of the microorganisms to reproduce without affecting their ability to ferment carbohydrates. This will can result in lower than expected milk/feed ratios because of lower than expected synthesis of microbial protein.

Also, avoid over-feeding RDP to the point that rumen ammonia concentrations markedly exceed bacterial requirements and MUN become high. Not only does it result in wastage of RDP, but there is also good evidence that it decreases flows of microbial protein to the small intestine (e.g., Boucher et al., 2007; Peter Robinson, personal communication).

3. Feed high-Lys protein supplements, or a combination of high-Lys protein supplements and a rumen-protected Lys supplement, to achieve concentrations of Lys in MP that come as close as possible to meeting the optimal concentration (Table 2).

Feeding low-Lys, high-protein feeds such as corn gluten meal is NOT consistent with balancing for Lys. In similar fashion, feeding larger amounts of dried distiller's grains with solubles (**DDGS**) also compromises balancing for Lys and requires feeding more RUP that would otherwise be needed to realize similar yields of milk protein. There may well be times when it is economical to feed larger amounts of DDGS, but it comes at the metabolic expense of having to feed more RUP.

4. Feed a "rumen-protected" Met supplement in amounts needed to achieve the optimal ratio of Lys and Met in MP.

Feeding a rumen-protected Met supplement, in conjunction with one or more of the aforementioned high-Lys protein supplements, is almost always necessary to achieve the correct Lys/Met ratio in MP (Table 3). To achieve the desired predicted ratio of Lys to Met in MP, and to ensure full use of the available MP-Lys for protein synthesis, it is important to use a realistic estimate for the amount of MP-Met provided by the Met product that you are feeding. Over-estimating the efficacy of a RP-Met supplement usually leads to disappointing production outcomes, and more often than not, leaves the nutritionist and dairy producer believing that balancing for Lys and Met has little value.

5. Do not overfeed RUP.

There are several disadvantages to overfeeding RUP. These include: 1) lowered concentrations of Lys and Met in MP (because most sources of supplemental RUP contain low concentrations of Lys, Met or both, relative to optimal concentrations in MP), 2) lowered milk production (because surplus RUP usually replaces fermentable carbohydrates in the diet, the primary substrates for synthesis of milk components), 3) a more expensive diet (because most sources of supplemental RUP are more expensive than most sources of nonfiber carbohydrates), and 4) increased urinary and fecal N (because of lowered conversions of feed protein to milk protein).

Identifying the optimum concentration of RUP in diet DM is challenging. The nutritional model that you use can be used as a guide, but it should not be used to provide the final answer. The reason is that there are too many factors that affect RUP requirements (e.g., intestinal supply of microbial protein, RUP digestibility, RUP-Lys digestibility, and concentrations of Lys and Met in MP) for current nutritional models to adequately consider and adjust requirements for. Each of these factors can have a significant effect on how much RUP is needed. Therefore, unless you are feeding an average diet to which your model validates, it is more than likely that your model will under or over estimate RUP requirements.

While disappointing, it must be emphasized that current models do not adjust MP requirements, and thus RUP requirements, for changes in predicted concentrations of AA in MP. This is a serious deficiency and until models are designed to predict

milk and milk protein yields from supplies of MP-Lys and MP-Met, just know that the MP requirement, and therefore the RUP requirement, for a given yield of milk and milk protein decreases with higher concentrations of Lys and Met in MP.

As a second step for identifying the optimum concentration of RUP in diet DM, it is suggested that insofar as feeding management allows, let the cows tell you how much they need. Don't be surprised, as a result of balancing for Lys and Met in MP, how little RUP is actually needed in the diet. Moreover, field experience indicates that cows are more responsive to changes in diet RUP content when RUP has a good AA balance vs. when the balance is not good. This makes sense because the nutritional potency of the RUP is greater when it has a good AA balance vs. a poor AA balance.

Benefits of Balancing for Lys and Met in MP

Balancing for Lys and Met in MP, using the steps as outlined, has led to many important benefits, both in research and on-farm implementation. The benefits include: 1) increased milk yields, 2) increased concentrations and yields of milk protein and fat, 3) reduced need for supplemental RUP for similar or greater component yields, 4) more predictable changes in milk and milk protein production to changes in RUP supply, 5) reduced N excretion per unit of milk or milk protein produced, 6) improved health and reproduction, and 7) increased dairy herd profitability. That these benefits to balancing for Lys and Met in MP have been achieved supports the conclusion that while other AA may become limiting, it seldom occurs before the recommended target levels for Lys and Met are achieved.

The most understood and appreciated benefits of improved Lys and Met nutrition are effects on lactation performance and the need for supplemental RUP. Increased milk component concentrations are the most visible and generally are the quickest to occur. It is no longer uncommon to hear reports of increases in milk protein concentrations of 0.20 to 0.25 percentage units and increases in milk fat concentrations of 0.10 to 0.15 percentage units...often on less dietary RUP. This does not mean that responses of this magnitude are always observed, but what it does mean is varying degrees of Lys and Met deficiency exist among herds and that one can expect variable effects on animal performance when balancing for Lys and Met. Increases in milk protein percentages are the most visible of the responses to better AA nutrition, and when observed, it should only be considered as the "the tip of the iceberg".

Increases in milk yield will also occur. This response is sometimes more difficult to measure because of the inherent greater variability in milk yield than milk protein concentrations on a day-to-day basis and the fact that research has shown that a smaller percentage of cows will respond with higher milk yields. Nevertheless, this is both an expected and observed response. Early studies indicated 2 to 5 lb more milk in early lactation (Garthwaite et al., 1999). More recent studies now have shown 5 to 10 lb more milk. Increased milk yields in early lactation may or may not be accompanied by increases in milk protein percentages if levels of Lys and Met in MP are not pushed high

enough. What field observations in particular have indicated is that if you see an increase in milk protein percentages, assume at least some increase in milk yield.

As mentioned earlier, a “feed advantage” to balancing for Lys and Met is the possibility for reduced RUP feeding while achieving similar or higher milk component levels and milk yields. Research and field observations alike indicate that it is no longer uncommon to see reductions in RUP of 1.0 to 2.0 percentage units of diet DM. This confirms that cows require “grams of amino acids” and not “grams of MP).

Two Research Studies that Highlight the Importance of Balancing Diets for Lys and Met on Efficiency of N Utilization

There are many good reviews in the literature summarizing the benefits of enriching rations in metabolizable Lys and Met that provide more detail about each of the above benefits (e.g., Garthwaite et al., 1999; NRC, 2001; Rulquin and Verite, 1993; Schwab et al., 2007, and Sloan, 2005). Two examples of experiments that were designed to demonstrate the value of increasing concentrations of Lys and Met in MP on increasing the efficiency of use of MP for milk and milk protein production were those of Noftsger and St-Pierre (2003) and Chen et al. (2011).

By increasing Met in MP from 1.73% to 2.09% (a 21% increase) to achieve a more favorable ratio with Lys (6.7-6.8% of MP), Noftsger and St-Pierre (2003) were able to reduce ration RUP from 7.6 to 6.4% of ration DM while achieving higher concentrations of milk protein (3.09 vs. 2.98%), a trend toward higher protein yields (1.44 vs. 1.38 kg), a trend toward higher milk fat (3.73 vs. 3.64%) and a trend toward higher fat yields (1.71 vs. 1.67 kg). There were no differences in milk production between the unbalanced and balanced diets (46.2 vs. 46.6 kg, respectively). The study involved both primiparous and multiparous cows. There were treatment by parity effects for protein production and milk fat percentage for the two treatments. Multiparous cows responded to the lower RUP, AA balanced diet with higher protein yields (1.65 vs. 1.51 kg) while yields were similar for the primiparous cows (1.24 vs. 1.25 kg), whereas the primiparous cows responded to the lower RUP, AA balanced diet with higher milk fat percentage (3.91 vs. 3.66) while percentages were similar for the multiparous cows (3.54 vs. 3.62).

In a recently completed study involving 5 dietary treatments, Chen et al. (2011) fed a positive control diet with 16.9% CP and 6.17% Lys and 1.85% Met in MP (NRC, 2001), a negative control diet with 15.7% CP and 6.60% Lys and 1.84% Met in MP (without Met supplementation), and the negative control diet supplemented with 3 different Met supplements (0.16% MetaSmart, 0.06% Smartamine M, and 0.06% Smartamine M + 0.1% Rhodimet AT 88). The Met supplements were fed in amounts to increase Met in MP such that the predicted Lys to Met ratio in MP was improved from 3.6 to 3.0. The diets were based on alfalfa and corn silage, and all diets contained high moisture corn, solvent extracted soybean meal, and a premix. The high protein diet also contained distillers dried grains and expeller soybean meal. The 70 primiparous and

multiparous Holstein cows averaged 147 DIM. Milk yields were similar across treatments (average = 41.7 kg) but content of protein was higher (average = 3.17%) for the three AA balanced diets than for the negative control (3.03%) and positive control (3.05%) diets. Milk fat percentages and yields were similar across treatments, but favored the positive control and Met supplemented diets. Production of energy-corrected milk was significantly higher for the MetaSmart diet as compared to the negative control diet but similar to the other three treatments. This study supports numerous field observations indicating production and economic advantages to feeding lower RUP, AA balanced diets. Income-over-feed costs (**IOFC**) were increased by about \$0.30 per cow/d as compared to feeding the higher protein diet.

Summary and Conclusions

As expected, the responses that one achieves in balancing diets for Lys and Met in MP depends on ones “starting point”. It should also be noted that where it is possible, field nutritionists with experience in balancing for Lys and Met will also lower dietary RDP and/or RUP if the previous diets allow. This has the benefit of often reducing the usual added expense of replacing low Lys protein supplements with high Lys protein supplements and the cost of adding one or more ruminant protected Met sources to the diet. When employing these feeding strategies, field nutritionists typically report a return on investment (**ROI**) of 2.5 or higher when balancing for Lys and Met in MP. Driver (2007) reported an average ROI of 3.35:1 in a 10-herd study conducted in 2006. The ROI ranged from 1.1 to 5.5 for the 10 individual herds. Increases in butterfat content and milk yields are also common and contribute to the favorable ROI.

Balancing diets for Lys and Met, because of the stated benefits, is an attractive option for increasing dairy herd profitability. Increases in IOFC approaching 40-50 cents per cow/d as a result of more precise balancing for RDP and RUP and balancing for Lys and Met have been reported by nutritionists.

Finally, it has been gratifying to see the return of high milk component concentrations (3.2-3.3% protein and 4.0% fat), along with improved health and breeding, in high producing Holstein herds. In retrospect, such levels of performance should probably be expected when the limiting AA are no longer limiting and cows are finally able to realize their genetic potential. Increases in milk protein concentrations are usually the first responses observed to balancing diets for Lys and Met, but nutritionists with years of balancing for Lys and Met would suggest that only as the most visible of the responses and “only the tip of iceberg” regarding the array of benefits of more adequately meeting the cow’s requirements for the most limiting AA.

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Table 1. Concentrations in CP of Lys and Met in milk¹, lean tissue¹ and rumen bacteria¹; suggested optimum concentrations in MP², and break-point estimates of required concentrations in MP for maximal content of milk protein³

	Lys	Met		Lys	Met
Milk	7.7	2.6	Brewer's grains	4.1	1.7
Lean tissue	6.4	2.0	Canola meal	5.6	1.9
Rumen bacteria	7.9	2.6	Corn DDGS	2.2	1.8
Optimum concentration	7.2	2.5	Corn gluten feed	2.7	1.6
"Required" (NRC, 2001)	7.2	2.4	Corn gluten meal	1.7	2.4
			Cotton seed	4.3	1.7
Alfalfa silage	4.4	1.4	Linseed meal	3.7	1.8
Corn silage	2.5	1.5	Soybean meal	6.3	1.4
Grass silage	3.3	1.2	Sunflower meal	3.6	2.3
Barley	3.6	1.7	Blood meal	9.0	1.2
Corn	2.8	2.1	Feather meal	2.6	0.8
Oats	4.2	2.9	Fish meal	7.7	2.8
Wheat	2.8	1.6	Meat meal	5.4	1.4

¹ Amino acid values for milk, lean tissue and rumen bacteria are from O'Connor et al. (1993), suggested optimum concentrations of AA in MP are from Doepel et al. (2004), and break-point estimates for required concentrations in MP for maximal content of milk protein and amino acid values for feeds are from NRC (2001).

Table 2. Ideal concentrations of Lys and Met in MP for milk protein yield in lactating dairy cows (% metabolizable protein)

Amino acid	Rulquin et al. (2001)	NRC (2001)	Doepel et al. (2004)	
			Segmented-linear model	Logistic model
Arginine	3.1		4.8	4.6
Histidine	3.0		2.4	2.4
Isoleucine	4.5		5.3	5.3
Leucine	8.9		9.4	8.9
Lysine	7.3	7.2	7.2	7.2
Methionine	2.5	2.4	2.5	2.5
Phenylalanine	4.6		5.2	5.5
Threonine	4.0		5.1	5.0
Tryptophan	1.7			
Valine	5.3		6.1	6.5

Table 3. Breakpoint estimates for required concentrations of Lys and Met in MP for maximal content and yield of milk protein for the NRC (2001), CPM, and AMTS models using the NRC (2001) data base (Schwab et al., 2009, Whitehouse et al., 2009)

Item	NRC Model				
	Optimal Lys	Optimal Met	Lys r^2	Met r^2	Optimal Lys/Met
Content of milk protein	6.80	2.29	0.82	0.75	2.97
Yield of milk protein	7.10	2.52	0.65	0.36	2.82
CPM Model					
Content of milk protein	7.46	2.57	0.83	0.73	2.90
Yield of milk protein	7.51	2.50	0.53	0.46	3.00
AMTS Model					
Content of milk protein	6.68	2.40	0.83	0.76	2.78
Yield of milk protein	6.74	2.31	0.65	0.38	2.92

SESSION NOTES