Amino Acids – The Required Nutrients…Matching Supply with Animal Requirements

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Introduction

It has been understood for decades that animals require amino acids (AA) for the synthesis of regulatory, tissue and milk proteins. It has also been known for many years that there are hundreds of different regulatory, tissue and milk 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 determined event, and that as a result, the AA composition of a protein is the same every time it is synthesized. And 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 absorbed nutrients, to meet requirements for protein synthesis. These AA were termed essential AA (EAA) (Rose, 1938). The remaining AA that were considered to be needed for protein synthesis but that could be synthesized by the animal organism were termed nonessential AA (NEAA). What this early understanding of AA nutrition 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 to the animal, rather than an unbalanced profile, provides for an opportunity to meet the animal's AA requirements with less dietary protein. This latter point has been exploited by the swine and poultry industry, for example, and by selective use of protein supplements and feed grade sources of the most limiting AA such as lysine (Lys) and methionine (Met), the AA requirements of most of these animals are being met with lower concentrations of dietary protein than otherwise possible.

The purpose of this paper is to provide brief reviews on the topics of: 1) the limiting AA theory, 2) limiting AA for lactating dairy cows, 3) a recent re-evaluation of the Lys and Met dose-response plots for the NRC (2001), CPM-Dairy (v.3.0.10) and AMTS.Cattle (v.2.1.) models, 4) the benefits of supplying the lactating dairy cow with an improved profile of absorbed AA, and 5) feeding strategies for trying to better match AA supply with AA requirements with a less than complete knowledge of requirements and less than perfect nutrition models. The intent 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 are too large to do otherwise, particularly if there is an interest in optimizing dairy herd profitability.

The Limiting Amino Acid Theory

Twenty AA are needed for protein synthesis. Ten AA are usually classified as essential and the remaining 10 as nonessential. As stated in the introduction, EAA are those AA that cannot be synthesized in animal tissues, or at least not at sufficient rates, to meet requirements for protein synthesis and other functions. Therefore, they must be absorbed. When absorbed in the profile that more closely resembles the profile as required by the animal, as has been demonstrated in numerous swine and poultry studies, the requirement for total EAA is reduced and their efficiency of use for protein synthesis is maximized. The NEAA are readily synthesized in animal tissues from each other, or from metabolites of intermediary metabolism as well as from surplus EAA. Unlike the EAA, there remains little evidence that the profile of absorbed NEAA is important for efficiency of use of absorbed AA for protein synthesis. Moreover, several experiments have demonstrated that NEAA as a group of AA do not become more limiting than EAA when dairy cattle are fed conventional diets (e.g., Doepel and Lapierre, 2010; Metcalf et al., 1996; Oldham et al., 1979; Schwab et al., 1976; 1982; Whyte et al., 2006). These observations indicate that when AA supplies approach requirements for total absorbable AA, requirements for total NEAA are met before the requirements for the most limiting EAA.

The term limiting AA has traditionally been used to identify the EAA that are in shortest supply “relative” to requirements. For example, the first limiting AA is that EAA supplied in the smallest amount “relative” to requirements. In like fashion, the second limiting AA is that EAA supplied in the second smallest amount “relative” to requirements.

The limiting AA theory is often described by the barrel and stave example. If the staves of a barrel are of different heights, relative to the full length of the barrel, then the volume of liquid that the barrel can hold is determined by the length of the shortest stave. The shortest stave is the most limiting...because it determines the capacity of the barrel. Extending the length of the shortest stave to that of the second shortest stave increases the capacity of the barrel; at this point, the two staves become co-limiting. While the capacity of the barrel has been increased, its full capacity will not be realized until all staves are of the right (required) length. In like fashion, efficiency of use absorbed EAA for protein synthesis (and other functions) will not be optimized unless the profile of EAA matches the profile as required by the cow.

It must be acknowledged that AA have functions other than for protein synthesis. For example, it is well documented that EAA can be used for the synthesis of NEAA (Doepel and Lapierre, 2010). Examples would include the well known examples of the synthesis of tyrosine from phenylalanine and the synthesis of cysteine from methionine and the more recent observation of the apparent important role that the branched-chain amino acids (leucine, isoleucine and valine) have in the synthesis of aspartate and glutamine in lactating porcine mammary tissue (Li et al., 2009). Amino acids are also key regulators of various pathological and physiological processes, including immune responses (Yoneda et al., 2009). Amino acids are also used for the synthesis of all of the other N-containing compounds in the body. There are dozens of such compounds. Examples would include hormones, neurotransmitters, creatine phosphate, purines and pyrimidines, histamine, the skin pigment melanin, the vasorelaxant nitric oxide, polyamines such as such as spermine and spermidine, etc. It is also well known that Met can be used for the synthesis of choline. For the most part, only small quantities of EAA are used for these purposes. As a result, when otherwise healthy animals are fed conventional diets, there is little reason to believe that any of these functions would significantly alter the ideal profile of EAA for lactating dairy cows.

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). This is because of their low concentrations in most of the feeds fed to lactating cows, relative to their apparent optimum concentrations in MP (see next section). In most cases, Met has been shown to be more limiting than Lys. However, Lys can become co-limiting with Met, or more limiting than Met, when feeds of corn origin provide most, or all, of the RUP in the diet (NRC, 2001).

Histidine (His) has been identified as first limiting, in a number of studies, when grass silage and barley and oat diets are 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). 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, leads the author to speculate that His may become the third limiting AA rather quickly 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.

Of particular interest is the effect of supplemental His on milk fat concentrations, without apparent regard for sequence of limiting AA for milk protein synthesis. In the experiment by Korhonen et al. (2000), postruminal infusion of 0, 2, 4, or 6 g/d of His into the cows increased milk, protein, and lactose yields in a linear fashion but caused a linear decrease in milk fat. Vanhatalo et al. (1999) also observed a decrease in milk fat percentage. Similar effects on milk fat percentage have also been observed in cows fed corn and alfalfa silage-based diets. Moon et al. (2004) obtained quadratic increases in milk yield, linear decreases in fat percentages and yield, with no effect on protein content or yield, when they infused 0, 7, 15, or 30 g/d of His i.v. into the cows. Doelman et al. (2008) added 2.5 g/L of His to the drinking water of lactating cows, also fed a corn and alfalfa silage-based total mixed ration, as a way to have some His escape ruminal degradation. Water intake tended to increase from 85.1 to 92.1L/d, concentrations of His in plasma tended to increase from 14.6 to 21.6μM, milk yield increased by 1.7L/d, and there were tendencies for protein yield to increase and fat percentage to decrease. And finally, subtraction of 24 g/d of His from an abomasal infusion of all amino acids (1,104 g/d) into cows fed a very low protein diet (9% CP) decreased milk protein yield by 186 g/d and increased milk fat yield by 181g/d (Weekes et al., 2006). Subtractions of 22 g/d of Met and 75 g/d of Lys had similar effects on decreasing protein yield and increasing fat yield.

It is important that research be conducted to establish the required concentrations of all EAA in MP for maximal content and yield of milk protein. This has been initiated by some groups and when completed should be valuable to nutritionists in their quest to confidently balance diets for AA for lactating dairy cows. However, until the ideal profile of EAA is determined, nutritionists are advised to take full advantage of current knowledge regarding optimal levels of Lys and Met in MP (see next section) and formulate diets accordingly. Most research and field evidence indicates that increasing the content of Lys in MP as high as reasonably possible by selecting high Lys protein supplements, using a “protected” Met supplement to meet the optimum Lys/Met ratio in MP for the model that you use, and taking care not to overfeed RUP, are sound suggestions for optimizing AA nutrition in lactating dairy cows and for increasing dairy herd profitability. It does not appear that the benefits of following these suggestions will be compromised or minimized because other AA have become limiting, because the target formulation levels for Lys and Met in MP for maximal content and yield of milk protein were arrived at from data from experiments where cows were fed a variety of diets without consideration for content of the other AA. Indeed, available evidence indicates that the requirements for Lys and Met in MP for maximal content and yield of milk protein will be higher than indicated when all EAA are in balance. For example, Doepel et al. (2004) suggests requirements for Lys and Met in MP of 7.2 and 2.5%, respectively, when using NRC (2001).

Target Formulation Levels for Lys and Met in MP

In recognition of the importance of Lys and Met in dairy cow nutrition in North America, NRC (2001) published dose-response plots that related changes in measured percentages and yields of milk protein to model-predicted changes in Lys and Met concentrations in MP. To determine what the "requirements" for Lys and Met in MP are when the NRC (2001) model is used to evaluate diets, the NRC committee used the indirect dose-response approach first described by Rulquin and Verite (1993). The approach has the "unique benefit" of allowing requirement values to be estimated using the same model as that used to predict concentrations of AA in MP. By using a rectilinear model to describe the dose-response relationships, breakpoint estimates for the required concentrations of Lys and Met in MP for maximal content of milk protein were determined to be 7.2 and 2.4%, respectively; corresponding values for maximal protein yield were 7.1 and 2.4%. Because they can be achieved rather easily, target levels for Lys and Met in MP have typically been suggested as 6.6 and 2.2%, respectively. Both values approximate 96% of the concentrations needed, according to NRC (2001), for maximal content and yield of milk protein. These estimates have served as important targets for routine users of the NRC (2001) model in their quest to increase milk component yields with lower intakes of RUP and lower predicted flows of MP.

Last year Schwab et al. (2009) re-evaluated the Lys and Met dose-response plots using the final version of the model, rather than the beta version that had been used previously. The same studies as used for NRC (2001) were used. Also, all steps, as stated in NRC (2001), were repeated. In brief, generating the dose-response plots involves 5 steps: 1) predicting concentrations of Lys and Met in MP for control and treatment groups in experiments in which postruminal supplies of Lys, Met, or both, were increased and production responses measured, 2) identifying "fixed" concentrations of 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 each Lys experiment that corresponds to the "fixed" level of Lys in MP and in each Met experiment that corresponds to the "fixed" level of Met in MP, 4) calculating "production responses" (plus and minus values) for control and treatment groups relative to the "reference production values", and 5) regressing the production responses on the predicted concentrations of Lys and Met in MP.

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. This was done for both of the CNCPS-based models because of their wide spread use in the dairy industry and the 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 would be different.

The result of the efforts of Schwab et al. (2009) and Whitehouse et al. (2009) are presented in Table 1. 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 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 conclude 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.

As expected, differences also existed between the results obtained with NRC, CPM-Dairy and AMTS.Cattle (Table 1). This was expected, as models differ in the approach for predicting supplies of AA. These differences led 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). Prediction models based on the factorial method require the assignment of AA values to model-predicted supplies of ruminally synthesized microbial protein, RUP, and if predicted, endogenous protein. CPM-Dairy (v.3.0.10) uses CNCPSv.5 and AMTS.Cattle (v.2.1.1) uses CNCPSv.6. The latest version of

CNCPS has expanded CHO pools, modified CHO A1-B1 degradation rates, the soluble fractions (e.g., sugar, NPN) 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.

Since 1999 when the original data base for developing the Lys and Met dose-response plots for NRC (2001) was developed, additional Lys and Met experiments have become available. Additionally, other ruminally protected Lys and Met supplements such as AminoShure^{TM}-L, Megamine-L^{TM} and MetaSmart® became available and used in experiments appropriate for inclusion in the data sets also become available that were used in these experiments. Therefore, the objectives of Whitehouse et al. (2010a) were to: 1) expand the Lys data base using data from experiments conducted since 2000 where postuminal supplies of Lys were increased by intestinal infusion or by feeding ruminally protected Lys supplements and 2) generate dose-response plots and breakpoint estimates for the required concentrations of Lys in MP for maximal content and yield of milk protein for “infusion” and “combined” treatments for the 3 models. Six additional experiments were identified where lactating Holstein cows were fed a basal, Lys-deficient diet and one or more amounts of Lys were continuously infused into the abomasum or duodenum or fed in ruminally protected form. Two experiments involved infused Lys, two experiments involved feeding Smartamine® ML and two experiments involved feeding Megamine-L^{TM}. In like fashion, the objectives of Whitehouse et al. (2010b) were to: 1) expand the Met data base using data from experiments conducted since 2000 where postuminal supplies of Met were increased by intestinal infusion or by feeding Smartamine® M or MetaSmart®, 2) eliminate observations in the data set with too much uncertainty about contributions of treatment to flows of MP-Met or where model-predicted concentrations of Lys in MP were lower than desired, and 3) generate dose-response plots and breakpoint estimates for the required concentrations of Met in MP for maximal content and yield of milk protein for “infusion only”, “Smartamine® M only”, and “MetaSmart® only” treatments for the three models. Seventeen additional experiments were identified where lactating Holstein cows were fed a basal, Met-deficient diet and one or more amounts of Met were continuously infused into the abomasum or duodenum or fed in ruminally protected form. Data from treatments involving encapsulated Met products from Eastman Kodak and Rumen Kjemi were removed because of limited information on either ruminal escape or intestinal release and because the products are not available commercially.

The results of Whitehouse et al. (2010a,b) are presented in Table 2. Again, differences were observed among the 3 models for the required concentrations of Lys and Met in MP for maximal content and yield of milk protein. Results support the findings of Whitehouse et al. (2009) that the predicted concentrations of Lys (and Met) in MP for maximal content and yield of milk protein are higher for CPM than for NRC or AMTS; a result of the fact that CPM predicts higher concentrations of Lys and Met in MP. Differences in the biology of the three models are such that AMTS and to a lesser extent CPM, predicted a greater range of Lys concentrations in MP than NRC (2001). Most notable were the lower predicted concentrations of Lys in MP of diets with large amounts of feeds of corn origin (corn silage, corn gluten feed, corn grain, and corn gluten meal), a result in part because of the markedly lower assumed levels of Lys in the RUP fraction of these feeds in AMTS (and CPM) as compared to NRC. This precluded being able to identify a “fixed” reference concentration of Lys in MP that was intermediate to the lowest and highest values in as many of the studies for AMTS. As a result, fewer observations could be used to generate the dose response plots for AMTS and CPM than for NRC.

Feeding Strategies for Balancing Diets for Lys and Met

The following feeding strategies have been shown to be effective in balancing diets for Lys and Met and have allowed producers to realize the benefits expected of balancing diets for AA. The obvious goals are to: 1) obtain the herds genetic potential for milk yield and component concentrations, 2) achieve optimum herd health, 3) increase conversion of feed CP to milk protein, 4) minimize wastage of dietary N, and 5) increase income-over-feed-costs and dairy herd profitability. A brief discussion of each step follows.

Step #1: Feed a blend of high quality forages, processed grains, and byproduct feeds to provide a blend of fermentable carbohydrates and physically effective fiber that maximizes feed intake, milk production, and yield of microbial protein

Microbial protein, based on research to date, has an excellent AA composition for lactating dairy cows. The average reported concentrations of Lys and Met in bacterial true protein approximate 7.9% and 2.6%, respectively; values that exceed the concentrations in nearly all feed proteins (NRC, 2001) as well as the optimal concentrations in MP as estimated by the 3 models (Table 2). Realizing maximal benefits of feeding a balanced supply of fermentable carbohydrates on feed intake, milk production, and yields of microbial protein requires use of high quality and appropriately processed feeds, adequate intakes of physically effective fiber, well-balanced and consistent diets, unlimited supplies of fresh water, and superior feed and bunk management.

Step #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 that you use, use the predicted requirements as a guide and fine tune according to animal responses. Monitor feed intake, fecal consistency, milk/feed ratios, milk fat concentrations, and MUN to make the final decision. A common target value for MUN is 10-12 mg/dl, but values lower than this is not uncommon in high producing cows.

Don’t short-change the cows on RDP…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 and production of 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 feeding RDP to the point that rumen ammonia concentrations markedly exceed bacterial requirements. 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).

Step #3: Feed high-Lys protein supplements to achieve a level of Lys in MP that comes as close as possible to meeting optimal concentrations (see Table 2)

For those using the NRC model, economics have been indicating "sweet spots" at values that are 0.92-0.94 of the optimum concentrations for Lys and Met in MP that are shown in Table 2. In some cases, the target values should be higher. With that said, and assuming model biases are appropriately reflected in the breakpoint estimates of the required concentrations of Lys and Met in MP that are presented in Table 2, then initial targets for Lys in MP would be 6.4% for NRC, 6.8% for CPM, and 6.4% for AMTS. For some nutritionists, these target values would be considered to be too low, but for those that have little or no experience in balancing for Lys and Met, these are good values from which to start.

If protein supplementation is required to achieve these target values for Lys, show a preference for only those high-Lys protein supplements (e.g., soybean, blood and fish meals) that you can be assured of that are high quality. In this case, "high quality" refers to products that are consistent from load to load in distribution of RDP and RUP and with "confirmed" highly digestible RUP where you are certain that RUP-Lys digestibility is not compromised. Your client should have confidence that the high-Lys protein supplements you have selected are providing the cow with as much Lys as you think it is.

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 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 over-feed RUP and under-feeding fermentable carbohydrates.

Selecting high-Lys protein supplements has been the only option, until the recent release of rumen-protected Lys (RP-Lys) products, to at least partially compensate for the low content of Lys in the RUP fractions from forages, grains and distiller's grains. Achieving target formulation levels for Lys in MP will become easier, and the value of lower Lys protein supplements extended, if the RP-Lys products can be demonstrated to be cost effective sources of MP-Lys.

Step #4: Feed a "rumen-protected" Met supplement in the 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 (see Table 2) when Lys . I continue to be surprised with first time evaluation of diets how often I see Lys to Met ratios in MP of 3.3 or higher…values as high as 3.5 and 3.6 are not uncommon. "Out of balance" Lys to Met ratios lowers the efficiency of use of MP for protein synthesis…and the more "out of balance" the ratios, the less efficient the use. This has been repeatedly shown in research and with on-farm AA balancing.

To achieve the desired predicted ratio of Lys to Met in MP (Table 1), and to ensure full use of the available MP-Lys for protein synthesis, one MUST use a realistic estimate for the amount of MP-Met provided by the Met product that you are feeding. Over-estimating the amount of the MP-Met that some of the Met supplements provide has been way too common. This is unfortunate because it leads to disappointing production outcomes, and more often than not, leaves the nutritionist and dairy producer believing that balancing for Lys and Met has minimal impacts on animal performance. Relying on the blood and milk protein content response approaches as being the most appropriate techniques for arriving at estimates of 'Met and Lys bioavailability', a summary of the available research indicates that Smartamine M clearly has the greatest efficacy as a source of MP-Met. The industry use of a Met bioavailability value of 80% appears reasonable when the manufacture's recommendations for mixing with other supplements and rations are followed. The data is not as consistent for Mepron M85 and MetaSmart as it is for Smartamine M, but it appears from most of the experiments that the Met bioavailability value for the two products is somewhere between 35 and 50%.

Research indicates no measurable effects of Alimet or Rhodimet AT88 on blood Met concentrations when fed to cows on Met-adequate diets, or on content of milk protein when fed to Met-deficient cows. Therefore, it appears that feeding HMB, in either the acid or salt form, has little or no replacement value for RP-Met supplements. It appears quite certain that the Met bioavailability of these two products fed under commercial situations is less than 5%. Pulse-dosing large amounts into the rumen have yielded apparent rumen escape values of 40-50%. However, this is not the way the products are fed commercially. Unlike

Smartamine M, Mepron M85 and MetaSmart, adding incremental amounts of these products to Met-deficient diets has not increased milk protein concentrations or blood Met concentrations.

In summary, don't be penny wise and pound foolish on the amount of supplemental Met that you feed. If one is going to make the investment in good Lys sources, make sure the cow can use every gram of the additional Lys that is being supplied for building protein. And finally, at least at the moment, I am a little uneasy about the Met values for CPM because based on some model comparison work that we have been doing, I think the Met values are a tad high. Therefore, I consider the required levels of Lys and Met in MP to be 6.9 and 2.4 for NRC (2.9/1 ratio), 7.3 and 2.6 for CPM (2.8/1 ratio) and 6.8 and 2.5 for AMTS (2.7/1 ratio), but with the caveat that aiming for values that are 0.92-0.94 of these may be the most profitable.

Step #5: Don't 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 are deficient in Lys, Met or both (fish meal is the only exception)], 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 NFC), 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. As a first step, it is critically important that one expresses RUP as a percentage of diet DM (as one does for RDP). There is no logical basis for expressing RUP as a percentage of CP…RDP provides peptides, AA and ammonia for rumen microorganisms and RUP supplies intestinally digestible AA for the cow. Too often, when RUP is expressed as a percentage of CP, “more RUP” in a diet results in less RDP in the diet because there is a targeted level of ration CP that the nutritionist is trying to maintain. This approach is not consistent with balancing diets for RDP, RUP and AA.

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. The nutritional model that you use can be used as a guide for determining RUP requirements, but it should not be used to provide the final answer. There are two reasons for this recommendation. First, there are too many factors that determine the cows’ requirement for RUP to allow the model to be very accurate. Three important factors affecting RUP requirements are: 1) supply of microbial protein, 2) RUP digestibility, and 3) the AA composition of RUP. Each of these factors can have a significant effect on how much RUP is needed. And second, 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.

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.

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. (2009).

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) was 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. (2009) 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.

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, even with current low milk prices and high feed costs. It is no longer uncommon to hear reports of increases in milk protein concentrations of 0.15 to 0.25 percentage units, increases in milk fat concentrations of 0.10 – 0.15 percentage units, and 2 - 4 lb more milk, and 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.

Using the described feeding strategies for optimizing diets for AA, it has been possible to lower dietary CP levels across all production groups while achieving improvements in percentages and yields of milk protein and fat. Additionally, because of the reduction of dietary RUP achieved by this approach, a frequent result by some nutritionists has been lower total concentrate costs by allowing the inclusion of lower cost feeds that can contribute well to total dietary NFC. This approach has been implemented with herds at all levels of milk production with equal effect.

And finally, it has been gratifying to see the return of high milk component concentrations (3.3-3.4% 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. Two conclusions: 1) consider observed increases in milk protein percentages as the most visible of the responses to improved AA nutrition…it is “only the tip of iceberg” regarding the array of benefits of more adequately meeting the cow’s requirements for the most limiting AA and 2) accepting low components because of “high production” is an excuse for poor AA nutrition.

Conclusions

It is encouraging to see that more and more dairy nutritionists are embracing the practice of balancing for Lys and Met in MP. For those who have embraced the practice and followed recommended feeding strategies for achieving more ideal concentrations of RDP and RUP in diet DM, and more ideal profiles of Lys and Met in MP, the economic rewards have been excellent. This is particularly true for the producers that are paid by the Class III component formulas where milk protein continues to be the most valued milk component. Return on investment has simply been too high to do otherwise, even when milk prices are low and feed prices are high. Benefits include: 1) increased yield of milk and milk components, 2) reduced N excretion per unit of milk or milk protein produced, 3) more predictable changes in milk and milk protein production to changes in RUP supply, 4) improved herd health and reproduction, and 5) increased herd profitability. Increases in milk protein and fat concentrations of 0.1-0.25 percentage units for protein and 0.1-0.15 for fat and returns on investment of 2.0 to 3.5 are typical. Increases in milk yield are more common in early lactation cows than late lactation cows, and can be rather significant if balancing for Lys and Met is started before calving. With high feed costs and low milk prices, an important benefit of AA balancing has been the opportunity to increase milk and milk component yields with less RUP supplementation and similar or lower feed costs.

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Table 1. Breakpoint estimates for required concentrations of Lys and Met in MP for maximal content and yield of milk protein for the NRC, CPM, and AMTS models using the NRC (2001) data base (Schwab et al., 2009 and 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	.82	.75	2.97
Yield of milk protein	7.10	2.52	.65	.36	2.82
	CPM Model				
Content of milk protein	7.46	2.57	.83	.73	2.90
Yield of milk protein	7.51	2.50	.53	.46	3.00
	AMTS Model				
Content of milk protein	6.68	2.40	.83	.76	2.78
Yield of milk protein	6.74	2.31	.65	.38	2.92

Table 2. Breakpoint estimates for required concentrations of Lys and Met in MP for maximal content and yield of milk protein for the NRC, CPM, and AMTS models using an updated data base (Whitehouse et al., 2010a,b).

Item	**NRC Model**				
	Optimal Lys	Optimal Met	Lys r^2	Met r^2	Optimal Lys/Met
Content of milk protein	6.89	2.32	.78	.69	2.97
Yield of milk protein	6.95	2.44	.58	.39	2.85
	CPM Model				
Content of milk protein	7.23	2.68	.69	.66	2.70
Yield of milk protein	7.36	2.74	.51	.42	2.69
	AMTS Model				
Content of milk protein	6.84	2.54	.73	.69	2.69
Yield of milk protein	6.74	2.49	.66	.45	2.71