Can Nutrient Synchrony Affect Performance of Forage-Fed Cattle?

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Introduction

Synchrony is defined as to represent or arrange to indicate coexistence or parallel occurrence. Thus nutrient synchrony would imply a parallel occurrence of nutrients for the ruminant animal to consume or be present in the diet and rumen. Thus by supplying energy and nitrogen sources concurrently, an increase or optimization of microbial efficiency should occur. The increase in microbial efficiency then should translate into an increase in animal performance that would not have otherwise been observed if the supply of energy and protein in the rumen had not been optimally synchronized. Increasingly, the need for optimized nutrient utilization to address increasing costs of production and environmental considerations will necessitate opportunities to improve nutrient synchrony.

For ruminant animals the degree of diet nutrient synchrony in the rumen is not always predicative of the animal performance response; likewise diet nutrient asynchrony is not always indicative of poor animal performance. Nutrient synchrony in the rumen occurs at some regular basis because there is nearly always a supply of energy and protein for microbial metabolism but the measure of nutrient synchrony is likely transient. Therefore, the desire to increase animal performance would seem to necessitate a greater degree of continual synchrony between energy and protein substrates in the rumen. In forage-fed ruminants an additional challenge occurs because of the variability in forage intake and forage chemical composition. What happens if we can actually achieve nutrient synchrony? The theory follows then that we should see an increase in ruminal metabolism (Herrera-Saldana et al., 1990; Richardson et al., 2003) compared to asynchronous diets. Likewise, an increase in intake and digestibility should occur. Finally, an increase in animal performance should occur through an increase in nutrient extraction and supply of the products of fermentation to the animal. More than 30 years ago it was suggested that in order to maximize microbial protein synthesis, sources of N and carbohydrates should be selected which share similar rates of fermentation (Johnson, 1976).

Challenges to Nutrient Synchrony

Pasture and forage intake

One of the greatest challenges that still face nutritionist, particularly those that work with forage-fed cattle, is the accurate measurement or estimation of forage intake.

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In the case of grazing cattle this difficulty is of particular concern (Bargo et al., 2003). Not knowing or having an accurate estimation of the forage intake is the first hurdle that must be overcome in the investigation of diet nutrient synchrony in pasture/forage-fed cattle. In the case of grazing cattle, the amount of forage that is consumed is often poorly understood (Forbes, 1988; Bargo et al., 2003). Additionally, the diurnal and daily variation in forage intake of grazing cattle complicates the process of diet nutrient synchrony (Gekara et al., 2005). The variation in forage intake inherently introduces asynchrony in the supply of dietary nutrients to both the ruminal microorganism and the animal itself in post-ruminal digestion.

Forage chemical composition

This challenge is two-fold, first estimating and accurately assessing the current chemical composition of the forage that is consumed. Numerous studies (Coleman and Barth, 1973; Fisher et al., 1991; Dubbs et al., 2003) have demonstrated the difference in chemical composition between forage harvested by hand for chemical composition assessment and the chemical composition of masticate samples from fistulated cattle. The second challenge is that samples must be collected across a wide variety of grazing management strategies, forage availabilities, forage species, growing conditions, forage morphological stages, and environmental conditions. The matrix of conditions that affect pasture forage chemical composition presents a daunting scenario for diet nutrient synchrony.

Cattle Requirements

A related issue to dietary nutrient synchrony is cattle nutrient requirements. Successful achievement of dietary nutrient synchrony is useless if the nutrients supplied are inadequate to meet cattle nutrient requirements for maintenance and the desired level of production (growth, lactation, and gestation). Cattle nutrient requirements are not static and exhibit a great deal of variation during the productive cycle of any beef animal. Therefore, not only do requirements change, but the response to nutrient supply is physiological state dependant.

Supplement interaction

If the basic underpinning of diet nutrient synchrony for forage-fed cattle is the forage base then the introduction of supplements is where manipulation of the diet and nutrient synchrony occurs. However, the inclusion of supplemental feeds creates a complexity in the feeding scenario that may result in improved or detrimental animal response (Moore et al., 1999). Supplemental feeds often times have characteristics that are different from the base forage utilized. The differences may be positive to the manipulation of diet synchrony; in contrast, the characteristics of the supplement may additionally complicate an asynchronous dietary nutrient supply. In that regard, negative associative effects would be detrimental to the process of dietary nutrient synchrony.

Determination of the level of synchrony or success in achieving synchrony in a diet is essential. Ultimately the success or failure of diet nutrient synchrony is measured by the animal’s responses such as BW gain, milk production, or carcass weight accreted. However, successful improvement in one or multiple ruminal measurements may not be indicative of successful live animal improvement. Nutritionists have a multi-dimensional problem to solve when attempting to achieve dietary nutrient synchrony in forage-fed cattle. The contributing factors of the forage base, cattle characteristics, supplements, and the final ruminal environment where the initial nutrient synchrony starts all present a complicated picture.

Strategies to Optimize Diet Nutrient Synchrony

Timing of feed delivery

A straight forward way to affect the possibility of diet nutrient synchrony in forage-fed cattle is through the timing and/or frequency of supplemental nutrients. In light of forage-fed, particularly pasture-fed cattle, the supply of forage or at least accessibility could be considered relatively constant. Variation in forage intake does occur with diurnal variation associated with grazing. Timing of supply of supplemental nutrients does not necessarily consider supplement energy or protein degradation rates and timing and degradation are not mutually exclusive. The supply of supplemental nutrients acknowledges the situation of nutrient deficiencies from forage-based diets and implicitly implies that supplementation could affect nutrient synchrony.

Supplement types

In the pursuit of diet nutrient synchrony in forage-based diets, the main types of supplements have been energy and protein-based. Moore et al. (1999) wrote an excellent review of the effects of different supplement types on animal performance, intake, and digestibility. The need for energy or protein supplementation implies an asynchrony of total available nutrients supplied by the forage base that results in less than optimal animal performance. Therefore, the addition of energy or protein should rectify the diet deficiency and achieve some increased level of synchrony of energy and/or protein in the diet. The compliment of energy and protein in supplements may increase the likelihood of diet nutrient synchrony in forage-fed cattle.

Form of supplemental nutrients

The form of the supplements offered can also affect the likelihood of nutrient synchrony in the diet of forage-fed cattle. Generalized energy supplement forms include starch-based, simple sugars (molasses), or fibrous sources (pulps and soybean hulls). Likewise, protein supplement forms include NPN, natural protein, degradable intake protein (DIP), or undegradable intake protein (UIP). The utilization of different supplement forms affects the degradation rate and ultimate availability of the targeted nutrients along with ancillary nutrients that are supplied by the supplement choice.

Balancing nutrient profiles

Direct formulation of supplements and total diets to balance the ratios of energy and protein or energy and protein fractions is a method that directly applies to nutrient synchrony. This approach attempts to balance the supply of ruminal energy substrate (TDN) and protein substrates (CP or DIP). The supply of TDN and protein are not necessarily equal in amount, but rather supply the substrates in appropriate proportions.

Moore et al. (1999) suggested that supplementation improved forage DMI when the forage ratio of TDN:CP was >7, indicating a deficiency of N. In general, the ratio approach has proved to be most beneficial for cattle consuming low quality forages in which DIP is limiting. The utilization of ratios of energy and protein substrates suggests that the source of energy is not nearly as critical as the proportion of the energy relative to the protein, particularly DIP. Work by a number of groups has demonstrated the successful utilization of grain-based starch supplements to affect animal performance (Daura and Reid, 1991; Bodine et al., 2001; Bodine and Purvis, 2003).

Utilization of Feed Delivery to Affect Nutrient Synchrony

Animal Performance

The spatial timing of the forage intake and supplement intake has the potential to affect animal performance thorough differential timing of the availability of energy and protein substrates. Kolver et al (1998) utilized dairy cows that were hand-fed harvested forage and supplemented with a corn-based supplement either at the same time the forage was offered (synchronous) or 4 hours after the forage was offered (asynchronous). The different spatial offering of forage and concentrate resulted in a different hourly ruminal degradable nitrogen to ruminal degradable total nonstructural carbohydrate ratio; however the daily mean ratio was not different. The synchronous offering of forage and concentrate minimized the hourly differences in N:energy ratio around the feeding events compared to asynchronous offering. However despite the differences in the hourly ratios those differences did not elicit substantial differences in cow BW change, milk yield, or milk component yield. So despite measurable ruminal differences in N:energy over time, there was no measurable differences in performance of dairy cows. Work of Richardson et al. (2003) examined the effect of calculated dietary synchrony index on growing lamb performance. Diet synchrony indices of three diets were 0.86 (synchronous), 0.76 (intermediate), and 0.63(asynchronous). The ADG of growing lambs offered diets that were formulated with different levels of nutrient synchrony were not different (mean 0.187 kg/d); likewise efficiency of gain (mean 0.178 kg/kg) did not differ among treatments with calculated dietary synchrony index. However, lambs fed the asynchronous diet had lower retained energy (0.079 MJ retained/MJ of intake) compared to lambs fed the intermediate or synchronous diets (0.095 MJ retained/MJ of intake). In this case, diets of different nutrient supply and release did not affect growing lamb performance in which lambs were program fed (Richardson et al., 2003). The total supply of nutrients was more influential than the rate of timing of supply of nutrients to lambs.

In a frequency of supplementation trial on ranches in Texas (Huston et al., 1999), cottonseed meal was supplied at three different frequencies (daily, 3x/wk, and 1x/wk) compared to a control of no supplemental feed. In one experiment, supplementation decreased % change in BW by 5.3% compared to non-supplemented control cows, but frequency had no effect on the magnitude of % of BW change, and had no effect on BCS change. In contrast in a second experiment, cottonseed meal supplementation decreased % change in BW by 6.4% compared to non-supplemented control cows and the decrease in % of BW change was greater with daily (-11%) compared to 3x/wk or

1x/wk (-13.6%). Likewise BCS change was less with increasing frequency of supplementation. In the case of the second experiment, the more consistent supply of protein and energy associated with cottonseed meal improved cow performance in grazing conditions in Texas. Huston et al. (1999) notes that even once per week supplementation was beneficial, which was true, but increased frequency of supply with cottonseed meal likely was more beneficial to ruminal fermentation patterns and overall nutrient metabolism. Similarly, Farmer et al. (2001a) reported less loss in both BW and BCS with increased frequency of supplementation of a 43% CP supplement to cows grazing tallgrass prairie forage. The increasing frequency of supplementation elicited a more positive response to the supplemental nutrient. This demonstrates the concept that infrequency of supplementation or asynchronous supply of nutrients may be detrimental to ruminal fermentation and overall animal performance, particularly when the supplement interval is extended.

In a number of trials utilizing mature cows and synchrony, the ability to elicit an improvement in animal response with timing of supplement supply can be accomplished particularly on low quality forages. In the situations in which supplement frequency did have an effect on cow performance, the forage base was of low quality and the additional supply of nutrients was beneficial. In contrast, when more sensitive models were utilized (Hunt et al., 1989; Kolver et al., 1998; Richardson et al., 2003), the ability of a synchronized total diet did not elicit an improvement in animal response. In these cases successful synchrony of the diet did not provide an adequate positive influence to affect performance.

Intake and Digestibility

If nutrient synchrony is to affect animal performance a concurrent change in intake and digestibility is likely warranted. In the work of Kolver et al. (1998) utilizing pasture forage-fed dairy cows, there was no increase in pasture DMI associated with synchrony of pasture and concentrate feeds offered. Thus, total DMI was not increased by synchronizing dietary pasture and concentrate feeding. The intake and digestibility of DM, OM, N, and NDF fraction of the diet was not affected by synchrony of pasture and concentrate offering. Currier et al. (2004b) examined the effect of supplemental frequency (daily compared to every 2 d) with different NPN sources on intake and flow from the rumen in fistulated steers. Source of supplemental NPN did not increase straw OM intake (OMI), but daily supplementation with NPN did tend to increase straw OMI compared to that of alternate day NPN supplementation; this effect was also true for total OMI in both steers (Currier et al., 2004b) and wethers (Currier et al., 2004a). However duodenal OM flow (g/kg BW) was similar between the two supplementation frequencies. The increased intake and digestibility data of Farmer et al. (2001) underscores the effect of supplement frequency on cow performance (Farmer et al., 2001). A linear increase in daily forage OMI was reported with increasing supplement frequency from 2 to 7 d/wk. There was a 20 g/kg of $BW^{0.75}$ increase in OMI from 2 d/wk to 7 d/wk supplementation frequency. Likewise, there was a linear increase in OM and NDF digestibility with increasing frequency of protein supplementation from 2 to 7 d/wk. The protein source was a natural protein, and thus the constant supply of protein and some additional energy from the supplement was more beneficial and likely elicited a more favorable nutrient synchrony profile than infrequent supplement supply. Bohnert et al. (2002 a,b,c) in a series of papers looked at the effect of supplement frequency with different protein degradability. In steers offered low-quality meadow hay (Bohnert et al., 2002a), a quadratic effect of supplement frequency (daily, every 3rd d, or every 6th d) of either DIP or UIP supplementation on hay intake and total OMI was reported. Total tract digestibility of OM tended to show a linear decrease with decreasing supplement frequency. In all cases, supplying protein more frequently to steers consuming low quality meadow hay improved forage and total intake and total tract digestibility. Likewise in wethers consuming low-quality meadow hay (Bonhert et al., 2002c), hay intake and total OMI increased linearly with increasing supplement frequency. In contrast, OM total tract digestibility was not affected by supplement frequency. This data would again imply that offering a more consistent supply of supplemental nutrients to achieve a more synchronous supply of energy and protein will improve intake/digestibility and likely animal performance, which was demonstrated by improved cow BW maintenance with more frequent supplementation (Bohnert et al., 2002c).

Forage quality does have an effect on the likelihood of nutrient synchrony being successful. High quality forages such as those used by Kolver et al. (1998) or Gekara et al. (2005) may not support diet nutrient synchrony success, most likely from the excess of N and a potential deficiency of energy. Even though ruminants have the ability to recycle N, a more consistent supply or a synchronized supply of N elicited a better response in terms of intake and digestibility compared to supplement situations where N recycling was expected to occur because of infrequent supplementation. Digestibility was affected by an overall input of nutrients and a consistent input of nutrients. Consistent input of nutrients likely supplied the ruminal microbes with much needed energy and protein substrates whereas infrequent supplementation required ruminal microbes to go without or limited the supply of needed substrates that, in turn, decreased digestibility and likely microbial efficiency.

Ruminal Function and Metabolism

Henning et al. (1993) examined the effect of pulse-dosing or gradual supply of energy and protein supplement combinations to a wheat straw diet on the ruminal metabolism in sheep. The combination of pulse-dosing energy and protein represented rapid synchronization of nutrients in the diet. A combination of pulse and gradual supply of both energy and protein represented an unsynchronized supply of nutrients in the diet. Finally the combination of gradual energy and protein supply represented a slow synchronized supply of nutrients. A gradual supply of energy compared to pulse-dosing tended to increase feed intake by approximately 5%. Total ruminal outflow (g/d) and microbial outflow (g/d) were increased by the gradual supply of energy compared to pulse dosed energy supply. Total ruminal outflow also tended to be increased by 10% with gradual protein supply compared to pulse-dosing of protein. However, microbial outflow was not affected by protein supply pattern. In contrast, true rumen digestibility was decreased 5.6% by gradual protein supply compared to pulse-dosing of protein, but energy supply pattern did not affect digestibility in the rumen. Similar to microbial outflow, true microbial efficiency (g of microbial N/kg of OM fermented) was increased by 2.3 g of N/kg of OM fermented with gradual supply of energy compared to pulse-dosing of energy, whereas nitrogen supply pattern had no effect. This data would seem to indicate that the timing of supply of energy has a greater effect on the success of nutrient synchrony than does the timing of protein supply. Likely this is a function of the ability of the ruminal microbes to store nitrogen and the ruminant animal's ability to recycle nitrogen, whereas the storage of carbohydrate and/or energy does not occur. Therefore, the synchronization of the energy supply is consumption dependant.

In the study of Bohnert et al. (2002b), the effect of frequency of supplementation and thus nutrient synchrony on ruminal metabolism was examined. On the day that all supplements were offered, ruminal DM fill increased linearly as the length of supplement interval increased. Likewise ruminal ammonia-N concentration increased as frequency of supplementation decreased, as did total VFA concentration. Ruminal pH decreased as supplement frequency decreased; an effect of the amount of supplement that was introduced on the day of supplementation. In contrast, on the day that only the daily supplement was offered, the trends were exactly opposite. Total VFA and ammonia N were greater for daily compared to frequent treatments. Therefore, on the day that all supplements were offered differences between treatments were a function of supplement amount. However on the "off" days, ruminal metabolism of steers that did not have daily supplements were less favorable compared to the daily-supplemented cattle.

The supply of energy through carbohydrates has as great of influence on nutrient synchrony success as maybe any other factor. Bacteria are limited in their ability to store carbohydrate and no mechanism exists for the animal to recycle energy back to the rumen. In light of the limitation of energy recycling, a consistent energy supply would be the most beneficial strategy. Finally, matching the nitrogen supply to the available energy may be the strategy to adopt, however that is not to say that synchrony through protein supply may not have benefit.

Effect of Energy Supplement and Form to Affect Nutrient Synchrony

Animal Performance

Brown and Johnson (1991) examined the source of supplemental energy to affect cull cow performance. Cows were offered ammoniated stargrass hay and thus adequate CP (11.6%) was available from the hay, but overall dietary energy supply was limiting and thus the need for energy supplementation. Energy supplementation (citrus pulp, molasses, and molasses +cottonseed meal) increased cow ADG by 0.23, 0.35, and 0.40 kg/d more than the control cows (0.45 kg/d). There was no difference in ADG between a digestible fiber source in citrus pulp, and sugar from molasses. The supplemental energy along with a natural protein from cottonseed meal allowed for improved animal performance because of a better nutrient supply.

Similarly Garcés-Yépez et al. (1997) examined different energy sources for growing steers fed bermudagrass hay. The energy supplements provided differential amounts of starch and NDF. Energy supplements were corn-soybean meal (C-SBM), wheat middlings, and soybean hulls. Energy supplements were also offered at two different levels, low (25%) and high (50%) of the estimated TDN intake. Steer ADG exhibited an inverse relationship with starch level in the supplement, particularly at the high level of energy supplementation. The energy provided by the supplements with greater fiber concentration were likely complimenting the protein source from the bermudagrass hay, whereas the energy supplied by the C-SBM did not match the digestion rate and supply of protein from the hay.

In another study that utilized different energy sources (high fiber or high grain) for growing heifers grazing bermudagrass, the addition of energy to the diet increased total gain and ADG of the grazing heifers (Bodine et al., 2001). There was no difference between energy sources for heifer performance and efficiency of supplement use. In this case, the DIP supply was key to this situation. The amount of DIP was similar between the two energy sources and formulated to meet the requirements of the heifers. Therefore supply of protein/nitrogen for ruminal use was comparable between the two treatments and resulted in similar performance.

In another study, Bodine and Purvis (2003) utilized corn, soybean meal and a combination of the two to supply energy to steers grazing tallgrass prairie. In these supplements C-SBM was the base supplement that supplied adequate dietary DIP. The amount of corn supplement offered provided the same amount of energy as C-SBM, whereas the amount of soybean meal supplement offered the same amount of DIP as C-SBM. Therefore, a different DIP:TDN ratio was achieved in each supplement. The supplement formulations have the potential for differential opportunities for nutrient synchrony within the supplements and total diet. Steer ADG was greater for the C-SBM supplement in which DIP and energy were balanced. Daily gain was decreased in the supplements that provided similar amount of energy or protein to equal the C-SBM treatment. Supplements that included corn did decrease the time of grazing by the cattle compared to the non-supplemented control or soybean only supplemented steers. Additionally, supplement conversion was greater for the soybean meal supplemented steers compared to the corn supplement steers, with the C-SBM steers intermediate. The increase in supplement conversion indicated a deficiency of DIP and the increase in conversion with C-SBM indicates that the tallgrass prairie was likely deficient in both energy and protein.

The effect of supplementation on performance can be a function of matching or synchronizing the availability of energy substrates from the supplement with the forage base. The effect of the energy supplement is more pronounced on high-quality forage. When the forage and supplement have nearly equal digestibility and forages have adequate N, forage intake generally suffers. This principle was reviewed by Moore et al. (1999) with the TDN:CP ratio above or below 7 being the critical value. The work by Daura and Reid (1991) and Bodine and Purvis (2003) indicate the key to utilization of energy sources is to supply adequate DIP in the total diet to match the dietary supply of energy thereby synchronizing the supply of digestible energy and available protein. By supplying adequate DIP in the diet, starch-based supplements can be utilized without outstanding negative associative effects.

Intake and Digestibility

In the work of Garcés-Yépez et al. (1997), hay DMI was not affected by energy supplement type, however, there was an effect of supplement level intake. Greater level of TDN supplementation resulted in a decrease in hay DMI. The depression in hay DMI was not energy substrate dependant; rather the decrease in hay DMI was an overall displacement of hay by the supplement. Even though there was an energy supplement source effect on animal performance, an intake effect attributable to supplement type was not apparent.

The use of corn-based energy supplements decreased steer grazing time on tallgrass prairie pasture and thus had an effect on intake and digestibility (Bodine and Purvis, 2003). The utilization of corn alone or, C-SBM supplement decreased both forage DMI and forage digestibility compared to non-supplemented control and soybean meal supplemented steers. The addition of soybean meal to corn supplement increased digestibility compared to the corn supplement. Therefore, balancing of supplemental energy and protein did positively affect forage intake and digestibility compared to energy alone. This trend was repeated in the total digestible OMI, in that the addition of protein to a starch energy source, resulted in synchrony of nutrient supply in the rumen and had a positive effect on ruminal function. Additionally, when steers that were supplemented with adequate DIP were provided additional energy, total OM intake and digestible OM intake were increased.

A protein supplement or two energy supplements, one high in fiber and one high in grain, were supplemented to steers consuming prairie hay (Bodine et al., 2001). Supplementation increased hay OMI compared to non-supplemented control steers, and protein supplementation increased hay intake to a greater extent. However, there was no difference between energy supplement source and both increased hay OMI. Likewise, supplementation increased total diet OM digestibility, but here fiber-based energy supplementation resulted in greater digestibility than grain-based energy supplementation. Examining the reported starch intake, it would be expected that there would be greater differences in hay OMI and forage digestibility. However, all diets were formulated to supply sufficient dietary DIP for ruminal digestion of the carbohydrate from the hay and the energy supplying supplement. Therefore, the key to maintaining acceptable intake and digestion of low-quality forages is to synchronize the supply of DIP and carbohydrate from energy supplements. This is a re-occurring theme and an important concept for nutrient synchrony in forage-fed animals.

Supplementation with different energy sources will alter forage intake. There are mixed results for the effect of energy supplementation and potential energy source synchrony on forage intake and digestibility. Again, the key in affecting forage intake and digestibility is the complimentary synchrony of DIP and energy in the total diet.

Rumen Function and Metabolism

Supplementation of low-quality tallgrass prairie with either protein or energy supplements resulted in lower pH values compared to forage alone (Bodine et al., 2001). The energy supplements resulted in lower pH values compared to protein supplementation, but there was no difference between starch or fiber-base energy supplements. Ammonia-N was increased with supplementation compared to non-supplemented steers mainly because the supplements provided additional CP compared to the forage. Likewise, providing supplements increased total VFA concentration and the energy supplements produced greater VFA concentrations compared with protein supplementation. Supplying starch from grain and balancing the diet for DIP resulted in synchronization of the energy and protein supply in the rumen and greater amounts of VFA were produced. In the synchrony experiment of Richardson et al. (2003), a supplements based on barley and beet pulp were supplied to a forage-based diet for lambs. After feeding these diets to lambs, there was no difference in ruminal pH, VFA concentration, or plasma urea-N as a result of energy source or level of synchrony. Plasma ammonia and microbial flow were increased by the barley-based supplement compared with the beet pulp diet. In this case there were not great differences in ruminal function and metabolism, however, the greater retention of energy with the synchronized diet may indicate the potential for improved performance.

Ultimately, the use of energy-based supplements will influence animal performance and forage utilization, potentially increasing or decreasing the opportunities for nutrient synchrony in the diet. Unfortunately the level of knowledge about these exact interactions is particularly situation specific and robust models that incorporate a broad range of forages and supplements and produce specific results are not widely available.

Effect of Protein Supplement and Form to Affect Nutrient Synchrony

Animal Performance

Protein supplementation has been equally examined as a method to improve forage-fed animal performance through synchrony of dietary components. To accomplish this, multiple sources and forms of protein supplementation have been examined, as well as combinations with sources of energy. Stateler et al (1995) examined the addition of different protein sources to compliment the energy supplied by liquid molasses. The addition of energy alone from molasses increased steer performance when grazing dormant bahiagrass forage. The addition of natural protein sources, SBM or blood-feather meal to liquid molasses, increased steer ADG compared to urea as a source of nitrogen. In the case of growing cattle, the supply of both DIP and UIP is crucial, and this was indicated by the increased ADG when steers were supplemented with the blood-feather meal by-pass protein sources. The best performance was achieved by the steers which were supplemented with a molasses slurry that contained urea and blood-feather meal that met metabolizable requirements. In this case nutrient synchrony of supplying energy from molasses and NPN from the urea was enhanced by the addition of bypass protein.

In three selected studies (Currier et al., 2004a; Farmer et al., 2004; Bohnert et al., 2002c) the effect of a progression in the type of N/protein supply on animal performance can be seen. Currier et al. (2004a) examined the effect of two different

NPN sources (urea or biuret) on mature cow performance. The release rate of NPN in the rumen from either urea or biuret resulted in no difference in cow performance, but performance was improved compared to the control. Farmer et al. (2004) examined the percent of DIP in a protein supplement (0 or 30%) coming from urea on cow performance when grazing tallgrass prairie. There was no effect of DIP percent from urea on cow performance, but natural protein (0% DIP from urea) was numerically better than a protein supplement containing 30% DIP from urea. Finally, Bohnert et al. (2002c) utilized either a protein that contained DIP or UIP protein sources. Either type of protein supplied improved cow performance compared to control cows, but the two protein supplements were not different. For mature cows consuming low-quality forage, the source of protein is not likely the first limiting factor in terms of cow BW, BCS, or calf birth weight; energy supply from the forage is likely limiting performance. The opportunity for diet nutrient synchrony likely exists, but is limited by the overall energy of the diet.

In ruminants fed low quality forages, the supplementation of protein has repeatedly improved animal performance. The improvement in performance general has occurred because of correcting a protein/N deficiency in the diet, thereby better synchronizing the supply of energy and protein in the rumen. In many cases the addition of protein into the system to provide some level of synchrony between energy and protein was positive regardless of the source. Likewise, increasing the proportion and/or amount of natural protein improved animal performance in a number of experiments. Increasing CP content of the diet does several things. One, it possibly allows for a greater opportunity of energy and protein synchrony just by having more protein available. Secondly, the additional supplement likely brings with it energy substrates that have different degradation rates than the forage, thereby increasing the diet nutrient synchrony opportunities. Finally, additional protein allows for nitrogen recycling in the ruminant animal which again may improve the diet nutrient synchrony opportunities in the rumen.

Intake and Digestibility

The source of NPN (urea or biuret) did not affect straw intake, DM digestibility, or fiber digestibility in either a lamb study (Currier et al., 2004a) or steer study (Currier et al., 2004b). Interpretation of these results in light of nutrient synchrony implies that any difference in release rate of the NPN source had little overall effect on intake and digestibility performance. The supply of N in the rumen, while important, is not the greatest factor controlling intake and digestion.

Similar to the work of Currier, Bohnert et al, (2004a,c) evaluated the effect of DIP compared UIP supplementation on forage intake and digestion. Protein supplementation did not increase hay DM intake in either trial. In this scenario Bohnert et al. (2004c) suggested the maximal NDF intake of 12.5 $g \cdot kg\ DM^{-1} \cdot d^{-1}$ was reached and thus intake was already maximized given the fiber level of the forage. Supplementation with either DIP or UIP increased DM and NDF digestibility compared to the control diet. It has been well documented that protein supplementation increases digestibility through supplying a complimentary or some measure of synchronous supply of protein for the ruminal microbes to utilize. It was suggested that, in this case, the UIP supplement resulted in an improved NDF digestibility because it actually provided a more moderate amount of DIP relative to the energy balance from the forage (Bohnert et al., 2004c). This idea would mirror that put forth by the work of Bodine, in that the ratio of DIP to energy is a key driver in animal performance, intake/digestibility, and metabolism, a concept that fits the idea of nutrient synchrony perfectly.

Non-protein nitrogen generally is not the protein source of choice for fiber digesting bacteria and, in most cases, supplemental NPN is not stimulatory to forage intake and digestibility. Additionally, differential release rates of NPN products do not stimulate intake or digestibility of low-quality forages. This a function of NPN supplement increasing the overall N supply in the rumen, but the ratios of nitrogen and protein specifically to energy are not in balance or synchronized to positively affect intake and digestibility. In contrast, increasing supplement CP concentration with natural protein sources has been shown to increase forage intake and digestibility, for just the reason stated previously. Natural protein does a better job of synchronizing the supply of ruminal degradable protein and energy within the rumen.

Rumen Function and Metabolism

In contrast to the lack of effect of NPN source on intake and digestibility, different NPN sources did have some limited effect on ruminal metabolism (Currier et al., 2004c). Ruminal pH was not affected by source of NPN supplementation nor was total VFA concentration. As expected, ruminal ammonia concentration increased with NPN supplementation compared to non-supplemented control, but biuret did decrease ruminal ammonia concentration compared to urea supplementation. Likewise plasma urea-N was increased for NPN-supplemented steers, but again the concentration of plasma urea-N was decreased for biuret-supplemented steers. The improved synchrony of N release from biuret with energy from the forage resulted in an increase in bacterial-N and bacterial-N synthesis for biuret-supplemented steers compared to urea-supplemented steers (Currier et al., 2004b). The increase in bacterial N synthesis should be indicative of an improved ruminal environment and availability of energy and protein substrates. Ultimately, however, there was no improvement in performance of cows fed biuret compared to urea (Currier et al., 2004a).

Supplying either supplemental DIP or UIP decreased ruminal pH compared to meadow grass hay-fed control steers and UIP supplementation tended to support a higher ruminal pH compared to DIP-supplemented steers (Bohnert et al., 2002b). Concentrations of VFA increased with protein supplementation compared to control and VFA concentration tended to be greater with DIP compared to UIP supplementation. The increase in total VFA production is likely as much a function of overall supplement ingredient profile than a protein effect on VFA production. Ruminal ammonia-N concentration was greater in the DIP-supplemented steers (Bohnert et al., 2002b), a result of the diet formulation; however, plasma urea-N concentration did not follow this trend (Bohnert et al., 2002a). As a result of the likely greater energy supply from the supplement ingredients and available ruminal protein, more bacterial-N was synthesized in steers supplemented with DIP compared with UIP (Bohnert et al., 2002a). The increase in bacterial-N flow would indicate a more favorable environment for bacterial synthesis, likely a function of the synchrony of energy from the forage and protein from the supplement. Bacterial protein is of great importance for grazing cattle, particularly those that are grazing low-quality forage.

The different release rates of urea and biuret resulted in different effects for ruminal metabolism and absorption of the excess ammonia and it's conversion to urea. However, this difference did not equate to differences in animal performance. When using natural protein sources, the true protein/N effect is confounded by the synchrony of protein and energy that natural protein supplies in the rumen. The energy supplied may not be great, but it is likely different that the forage in terms of degradation rate and products of fermentation, thus providing an improvement in the ruminal environment.

Conclusions

The opportunity to utilize nutrient synchrony to affect forage-fed ruminant animal performance is influenced by a multitude of factors. There exist a number of nutritional management challenges for forage-fed ruminants that will limit the opportunity to address nutrient synchrony. The challenges include accurately estimating forage intake and chemical composition, precise knowledge of animal requirements, and a more complete understanding of the forage-supplement matrix of interaction. More complete information surrounding these nutritional challenges will allow ruminant nutritionist to next address nutrient synchrony for forage-fed ruminants.

In many situations the forage system alone, particularly low-quality forages, does not likely allow for full genetic expression of performance of the animal. Likewise the forage base alone generally provides an asynchronous diet in regards to the release and amount of important nutrients. When additional feed is introduced to provide additional nutrients in an attempt to synchronize nutrient supply, there can be negative effects. In situations in which moderate to high-quality forages are consumed, substitution of forage for supplement occurs. Additionally, the introduction of antagonistic feedstuffs that result in negative associative effects may compound the asynchronous nature of the total diet. The rumen is a robust environment capable of accommodating a range of dietary situations. However, the rumen does not function as a storage location for energy in the ruminant animal. The limitation of energy storage is likely a limitation in regards to total diet nutrient synchrony. Measurement of in situ degradation rates of protein and fiber fractions and total protein and fiber amounts is possible for all feedstuffs. However, simply matching these measured chemical compositions and predicted degradation rates will not be sufficient to elicit dietary nutrient synchrony alone. Ultimately, addressing the proportions of energy, protein, organic matter, and or degradable intake protein in combination with many other factors are plausible methodologies to address total diet nutrient synchrony.

References

Bargo, F., L.D. Muller, E.S. Kolver and J.E. Delahoy. Invited Review: Production and digestion of supplemented dairy cows on pasture. J. Dairy Sci. 86:1.

Bodine, T.N and H.T. Purvis II. 2003. Effects of supplemental energy and/or degradable intake protein on performance, grazing behavior, intake, digestibility, and fecal and blood indices by beef steers grazed on dormant native tallgrass prairie. J. Anim. Sci. 81:304.

Bodine, T.N., H.T. Purvis II and D.L. Lalman. 2001. Effects of supplement type on animal performance, forage intake, digestion, and ruminal measurements of growing beef cattle. J. Anim. Sci. 79:1041.

Bohnert, D.W., C.S. Schauer, M.L. Bauer and T. DelCurto. 2002a. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: I. Site of digestion and microbial efficiency. J. Anim. Sci. 80:2967.

Bohnert, D.W., C.S. Schauer, S.J. Falck,and T. DelCurto. 2002b. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: II. Ruminal fermentation characteristics. J. Anim. Sci. 80:2978.

Bohnert, D.W., C.S. Schauer and T. DelCurto. 2002c. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: Cow performance and efficiency of nitrogen use in wethers. J. Anim. Sci. 80:1639.

Brown, W.F. and D.D. Johnson. Effects of energy and protein supplementation of ammoniated tropical grass hay on the growth and carcass characteristics of cull cows. J. Anim. Sci. 69:348.

Coleman, S.W. and K.M. Barth. 1973. Quality of diets selected by grazing animals and its relation to quality of available forage and species composition of pastures. J. Anim. Sci. 36:754.

Currier, T.A., D.W. Bohnert, S.J. Falck and S.J. Bartle. 2004. Daily and alternate day supplementation of urea or biuret to ruminants consuming low-quality forage: I. Effects on cow performance and the efficiency of nitrogen use in wethers. J. Anim. Sci. 82:1508.

Currier, T.A., D.W. Bohnert, S.J. Falck, C.S. Schauer and S.J. Bartle. 2004. Daily and alternate day supplementation of urea or biuret to ruminants consuming low-quality forage: II. Effects on site of digestion and microbial efficiency in steers. J. Anim. Sci. 82:1518.

Currier, T.A., D.W. Bohnert, S.J. Falck, C.S. Schauer and S.J. Bartle. 2004. Daily and alternate day supplementation of urea or biuret to ruminants consuming low-quality forage: III. Effects on ruminal fermentation characteristics in steers. J. Anim. Sci. 82:1528.

Daura, M.T. and R.L. Reid. 1991. Energy and protected protein supplements to lambs on endophyte-infected tall fescue pasture. J. Anim. Sci. 69:358.

Dubbs, T.M., E.S. Vanzant, S.E. Kitts, R.F. Bapst, B.G. Fieser and C.M. Howlett. 2003. Characterization of season and sampling method effects on measurement of forage quality in fescue-based pastures. J. Anim. Sci. 81:1308.

Farmer, C.G., R.C. Cochran, D.D. Simms, E.A. Klevesahl, T.A. Wickersham and D.E. Johnson. 2001. The effects of several supplementation frequencies on forage use and the performance of beef cattle consuming dormant tallgrass prairie forage. J. Anim. Sci. 79:2276.

Farmer, C.G., B.C. Woods, R.C. Cochran, J.S. Heldt, C.P. Mathis, K.C. Olson, E.C. Titgemeyer and T.A. Wickersham. 2004. Effect of supplementation frequency and supplemental urea level on dormant tallgrass-prairie hay intake and diegestion by beef steers and prepartum performance of beef cows grazing dormant tallgrass-prairie. J. Anim. Sci. 82:884.

Fisher, D.S., J.C. Burns, K.R. Pond, R.D. Mochrie and D.H. Timothy. 1991. Effects of grass species on grazing steers: I. Diet composition and ingestive mastication. J. Anim. Sci. 69:1188.

Forbes, T.D.A. 1998. Researching the plant-animal interface: The investigation of ingestive behavior in grazing animals. J. Anim. Sci. 66:2369.

Garcés-Yépez, P., W.E. Kunkle, D.B. Bates, J.E. Moore, W.W. Thatcher and L.E. Sollenberger. 1997. Effects of supplemental energy source and amount on forage intake and performance by steers and intake and diet digestibility by sheep. J. Anim. Sci. 75:1918.

Gekara, O.J., E.C. Prigge, W.B. Bryan, E.L. Nestor and G. Seidel. 2005. Influence of sward height, daily timing of concentrate supplementation, and restricted time for grazing on forage utilization by lactating beef cows. J. Anim. Sci. 83:1435.

Henning, P.H., D.G. Steyn and H.H. Meissner. 1993. Effect of synchronization of energy and nitrogen supply on ruminal characteristics and microbial growth. J. Anim. Sci. 71:2516.

Herrera-Saldana, R., R. Gomez-Alarcon, M. Torabi and J.T. Huber. 1990. Influence of synchronizing protein and starch degradation in the rumen on nutrient utilization and microbial protein synthesis. J. Dairy Sci. 73:142.

Hunt, C.W., J.F. Parkinson, R.A. Roeder and D.G. Falk. 1989. The delivery of cottonseed meal at three different time intervals to steers fed low-quality grass hay: Effects on digestion and performance. J. Anim. Sci. 67:1360.

Huston, J.E., H. Lippke, T.D.A. Forbes, J.W. Holloway and R.V. Machen. 1999. Effects of supplemental feeding interval on adult cows in western Texas. J. Anim Sci. 77:3057.

Johnson, R.R. 1976. Influence of carbohydrate solubility on non-protein nitrogen utilization in the ruminant. J. Anim. Sci. 43:184.

Kolver, E., L.D. Muller, G.A. Varga and T.J. Cassidy. 1998. Synchronization of ruminal degradation of supplemental carbohydrate with pasture nitrogen in lactating dairy cows. J. Dairy Sci. 81:2017.

Moore, J.A., M.H. Brant, W.E. Kunkle and D.I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77(Supp 2): 122.

Richardson, J.M., R.G. Wilkinson and L.A. Sinclair. 2003. Synchrony of nutrient supply to the rumen and dietary energy source and their effects on the growth and metabolism of lambs. J. Anim. Sci. 81:1332.

Stateler, D.A., W.E. Kunkle and A.C. Hammond. 1995. Effect of protein level and source in molasses slurries on the performance of growing cattle fed hay during winter. J. Anim. Sci. 73:3078.

SESSION NOTES