**Enhancing the Efficiency of Nutrient Utilization in Cattle**

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### *Why It Is Important to Enhance Nutrient Utilization Efficiency in Cattle*

The efficiency of conversion of dietary nutrients, in particular nitrogen (N), into milk or meat protein is low in ruminants. In dairy cattle, less than 30% of dietary N is captured into milk protein (VandeHaar and St-Pierre, 2006). Similarly, up to 90% of feed N is excreted in urine and feces, with only a small fraction (10 to 20%) being converted into meat protein in beef cattle (Satter et al., 2002). Since feed is the major contributor to total operational costs, and protein is typically the most expensive component of most diets, the capture of only a small proportion of dietary N into saleable product reduces on-farm profitability (VandeHaar and St-Pierre, 2006). This is especially critical today because of the rising and volatile cost of traditional protein ingredients including soybean meal and the current low milk and cattle prices, which are severely eroding profit margins.

Besides its impact on economic returns, the high excretory losses of N, in particular, urine urea-N, can also compromise ecological health. Compared to fecal N, urine urea-N is more prone to being broken down and altered into various compounds including ammonia and nitrates that can pollute the atmosphere, and ground and surface water (VandeHaar and St-Pierre, 2006). Although cattle producers in the U.S. do not currently face direct costs associated with the loss of N in urine and feces, the implementation of taxes on N excretion on farms in some European countries including the Netherlands is a harbinger of the future changes in environmental policies and regulation (Higgs et al., 2012). Moreover, the recent lawsuits alleging nitrate pollution of groundwater from agricultural activities in the Yakima Valley, WA, and the three rural counties neighboring Des Moines, IA, are a strong indication of the rising tide of change with regards to environmental accountability in the U.S. (Scheider, 2015). Therefore, as nutrient management policies and regulations will become more stringent, and as feed costs continue to rise, viability of both the dairy and beef sectors is dependent on the implementation of dietary strategies that will enhance the efficiency of N utilization.

### *Nitrogen Metabolism in the Rumen and Urea-N Recycling*

The indiscriminate nature of dietary protein degradation by the rumen microbes is one of the major causes of the low efficiency in N use by cattle (Calsamiglia et al., 2010). Dietary protein, is broken down to peptides, amino acids and ammonia, which can all be used to support microbial growth (synthesis of microbial protein) as long as fermentable energy is available. However, excess peptides and amino acids are further broken down to ammonia, and the bulk of ammonia that is not used for microbial growth is then lost from the rumen through absorption into blood. This loss of ammonia from the rumen is one of the major reasons for the low efficiency in N use. Since it is neurotoxic at high blood concentration, absorbed ammonia is converted to urea-N in the liver. Thereafter, the urea-N is released into blood (blood urea-N), and can then either be recycled back to the rumen or excreted in urine (urine urea-N). It is estimated that between 40 and 80% of urea-N that is synthesized in the liver can be recycled back to the rumen and used to support microbial growth (Lapierre and Lobley, 2001). The proportion that is recycled and used for microbial growth is dependent on a number of factors, including the supply of fermentable energy from the diet. The remainder (20 to 60%) is what is then irreversibly lost to the environment as urine urea-N and can potentially compromise ecological health.

***Dietary Strategies to Enhance Nitrogen Utilization Efficiency in Cattle***

Limiting the amount of ammonia that is lost from the rumen and increasing the proportion of blood urea-N that is recycled back to the rumen could potentially improve the efficiency of N usage in cattle (Calsamiglia et al., 2010). In one distillers grains study (Chibisa and Mutsvangwa, 2013), we attempted to reduce the amount of ammonia that is lost from the rumen by feeding a low- compared to a high-protein diet (15.2 vs. 17.3% CP of diet DM) to lactating cows. As expected, cows fed the low-protein diet consumed less N, which resulted in a lower concentration of ammonia in the rumen compared to cows fed the high-protein diet (Table 1). In addition, the amount of urea-N that was synthesized in the liver and blood urea-N concentration were also lower in cows that were fed the low-protein diet suggesting that reducing dietary CP concentration also limited the amount of ammonia that was lost from the rumen. Moreover, cows that were fed the low- compared to the high-protein diet also excreted 21.8% less total N and 30.1% less urine urea-N (Table 1), which is desirable from an environmental stewardship standpoint. Others (Spek et al., 2013; Arriola Apelo et al., 2014) reported similar findings when feeding low-protein diets to lactating cows, which is a strategy that can also reduce feed costs.

Although it is effective in limiting the excretion of urea-N in urine, reducing dietary CP content can also potentially cause a decrease in milk and milk component yields, which is undesirable for economic reasons. This loss in production results in from the low dietary protein content causing a deficiency in ruminally-degradable protein (RDP), which compromises rumen function and reduces dry matter intake (DMI), microbial protein synthesis or the supply of key amino acids required for milk protein production (Giallongo et al., 2015). Ultimately, there is a decrease in performance due to the metabolizable protein and energy requirements of the lactating cow not being met. In our study (Chibisa and Mutsvangwa, 2013), although feeding diets containing 15.2 compared to 17.3% CP did not impair DMI, it resulted in a decrease in milk and milk protein yield (3.6 and 0.14 kg/d, respectively; Table 2). Therefore, this decrease in production performance was possibly caused by a deficiency in dietary RDP that resulted in a decrease in rumen ammonia concentration and compromised microbial growth. Kristensen et al. (2010) and Spek et al. (2013) also made similar observations, and this makes the feeding of low-protein diets to lactating cows an economically risky strategy to adopt on farms.

Urea recycling is an important evolutionary adaptation mechanism that enables ruminants to survive on low-protein diets as a greater proportion of blood urea-N is returned back to the rumen instead of loss in urine (Lapierre and Lobley, 2001). Therefore, there has been interest in determining whether it is possible to fully harness this "N salvage" mechanism so as to prevent a deficiency in RDP supply when lactating cows are fed lower protein diets. In our study (Chibisa and Mutsvangwa, 2013), we had anticipated that feeding a low compared to a high-protein diet (15.2 vs. 17.3% of diet DM) would increase the amount of urea-N recycled back to the rumen. This would have then buffered the rumen from the decrease in dietary RDP supply, thereby preventing a decrease in milk and milk protein yield due to compromised microbial growth. However, although the amount of recycled urea-N that was used for microbial growth was greater in cows fed the low- compared to the high-protein diet (11.5 vs 8.5%), it was not substantial enough to prevent a decrease in microbial growth (Fig 1 and 2). Ultimately, this contributed to the compromised production performance in our study (Chibisa and Mutsvangwa, 2013). Similarly, although the amount of urea-N that was recycled back to the rumen was greater (23.2 vs. 8.1%) in cows fed a low compared to a high-protein diet (12.9 vs. 17.1% of diet DM), it did not prevent a decrease in milk yield (36 vs. 42 kg/d; Kristensen et al., 2010). Spek et al. (2013) also reported a 3.4 kg decrease in milk yield despite a greater proportion of urea-N synthesized in the liver being recycled back to the rumen in cows fed diets containing 11.6 compared to 15.4% CP (DM basis).

On the contrary, feeding a low compared to a high-protein diet (14.9 vs. 17.5% of diet DM) to lactating cows did not compromise milk production (Mutswangwa et al., 2016). This was attributed to a greater tendency for the use of recycled urea-N for microbial growth in cows fed the low- compared to the high-protein diets. However, although not reported, the low-protein diets contained a higher amount of starch compared to the high-protein diets as a result of the higher inclusion level of barley grain (38.3 vs. 30.8%). Therefore, this greater supply of readily fermentable energy in cows fed the low- compared to high-protein diet could have enhanced the recycling of urea-N to the rumen and its use to support microbial protein synthesis. However, Recktenwald et al. (2014) did not observe an increase in the capture of recycled urea-N for microbial growth in the rumen after increasing the amount of dietary starch (28.7 vs. 22.0% of diet DM) in diets containing 15.2 compared to 16.7% CP. Given these contradictory responses, more research is warranted to shed more light on regulation of urea-N recycling in dairy cows and whether this "N salvage" mechanism could be fully harnessed to prevent production losses associated with feeding low-protein diets.

Another strategy that has received considerable interest in recent years, is the supplementation of rumen-protected amino acids in low-protein diets (Giallongo et al., 2015). Supplementation compensates for the deficiency in metabolizable protein supply by providing specific additional amino acids to support milk and milk protein synthesis. To date, most of the research on amino acid supplementation have primarily focused on lysine, methionine and histidine. Lysine and methionine are the most limiting amino acids for milk protein production in typical corn-alfalfa forage-based diets (NRC, 2001), whereas histidine has been reported to be a limiting amino acid in corn-silage based diets that are deficient in metabolizable protein (Lee et al., 2012). Provision of these rumen-protected amino acids (lysine, methionine and histidine) has been shown to be effective in preventing a decrease in milk and milk protein yield when lactating cows are fed low-protein diets (Lee et al., 2012; Arriola Apelo et al., 2014; Giallongo et al., 2015). Therefore, this strategy is beneficial in reducing N loss to the environment while also maintaining production performance; and depending on the cost of including supplemental rumen-protected amino acids in the diet, it could also be economically prudent.

Currently, there is a growing body of research on the dietary inclusion of compounds that can modify/reduce the rate and extent of digestion of protein in the rumen and, therefore, limit the loss of ammonia into blood. Tannins, which are plant secondary metabolites, are an example of such compounds that can potentially improve protein utilization when included in moderate amounts (up to 4% of diet DM) in the diet (Makkar, 2003). Tannins bind dietary protein to form a tannin-protein complex that is stable in the rumen (pH 3.5 to 7.5) and cannot be degraded by the rumen microbes. However, the tannin-protein complex breaks down in the abomasum as a result of the low pH (< 3.5) to release the protein for potential enzymatic digestion (Jones and Mangan, 1977). In addition, tannins also reduce the growth and activity of the microbes that degrade protein in the rumen. Ultimately, this reduces the concentration of ammonia in the rumen and its loss into blood, which in turn reduces the synthesis and loss of urea-N in urine.

Although beneficial in improving N utilization, feeding an excessive amount of tannins can also potentially compromise production performance. For instance, feeding up to 1.8% (of diet DM) quebracho-chestnut tannin extracts resulted in a decrease in urine urea-N excretion (Aguerre et al., 2016). However, Aguerre et al. (2016) also noted a decrease in dry matter intake, nutrient digestibility and milk protein yield as the tannin inclusion level increased (0.45, 0.9 and 1.8% of diet DM), which led them to recommend limiting the amount to 0.45% to prevent a decrease in lactation performance. On the contrary, inclusion of up to 3% quebracho or chestnut tannin extracts did not compromise dry matter intake, nutrient digestibility or milk yield and composition (Dschaak et al., 2011; Liu et al., 2013). Since the reasons for this discrepancy are still not known, there is a need for additional research to fine-tune the use of this strategy such that the decrease in urine urea-N excretion is not accompanied by a reduction in milk and milk component yield. In addition, besides the commercially-sourced tannin extracts (primarily from countries like Argentina and Brazil), there is a need for more research on the use of local sources of tannins including the tannin-rich forages (e.g., sainfoin and birdsfoot trefoil) and by-products (e.g., grape pomace), which have also been reported to improve N utilization in a handful of studies (Hymes-Fecht et al., 2013; Ishida et al., 2015; Huyen et al., 2016).

***Conclusion:***

Given the rising cost of feed, mounting consumer pressure to reduce the environmental cost of milk and meat production, and the current low milk and cattle prices, it is imperative that producers adopt feeding strategies that enhance the efficiency of conversion of dietary nitrogen into saleable products (milk or meat). Several strategies including reducing dietary protein concentration and feeding compounds that limit protein degradation in the rumen (e.g., tannins) have been shown to be effective in reducing feed costs and urinary N excretion; however, they can also potentially compromise production performance. Therefore, besides fine-tuning the existing ones, there is a need for development of other novel strategies to effectively address the productivity, profitability and environmental sustainability-related challenges that dairy and beef producers in the U.S. are facing today.

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**Table 1.** Rumen ammonia and blood urea-N concentration, and urine N and urine urea-N excretion in lactating cows fed a low- compared to a high-protein diet

| | Diet | | | |
|---|---|---|---|---|
| **Item** | **15.2% CP** | **17.3% CP** | **SEM** | ***P*-value** |
| **Rumen ammonia, mg/dL** | 10.9 | 12.7 | 0.95 | 0.04 |
| **Blood urea-N, mg/dL** | 15.9 | 19.0 | 1.12 | <0.01 |
| **Urine N, g/d** | 212 | 271 | 18.9 | <0.01 |
| **Urine urea-N, g/d** | 79 | 112 | 6.5 | <0.01 |

**Table 2.** Dry matter intake, milk and milk protein yield in lactating cows fed a low- compared to a high-protein diet

| | Diet | | | |
|---|---|---|---|---|
| **Item** | **15.2% CP** | **17.3% CP** | **SEM** | ***P*-value** |
| **Dry matter intake, kg/d** | 28.7 | 29.2 | 0.85 | 0.29 |
| **Milk yield, kg/d** | 40.3 | 43.9 | 1.53 | <0.01 |
| **Milk protein yield, kg/d** | 1.22 | 1.36 | 0.049 | <0.01 |

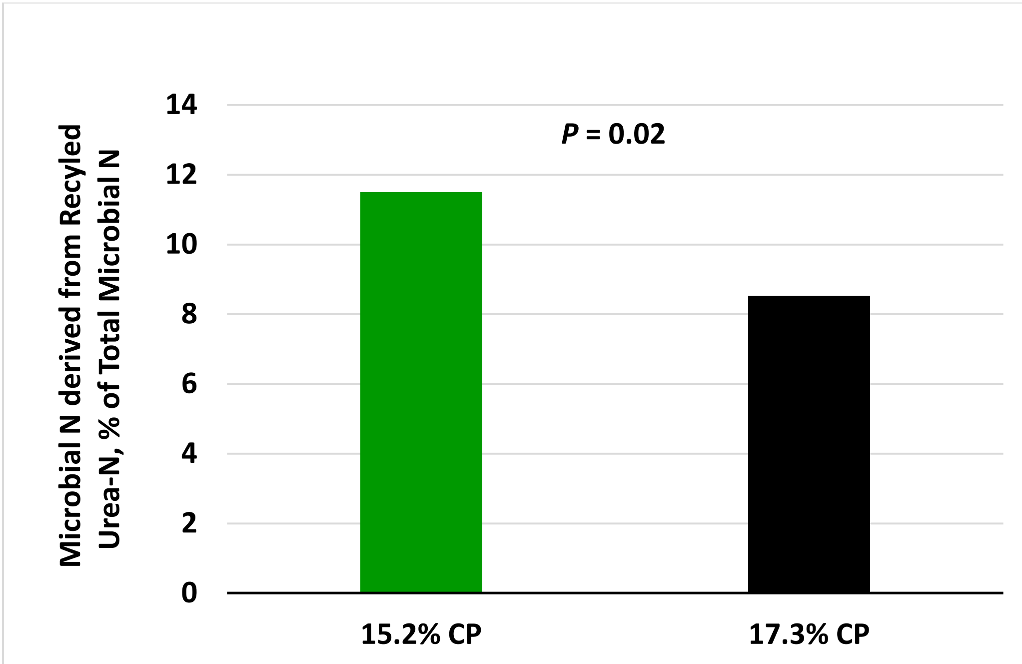


**Fig 1.** Use of recycled urea-N for microbial growth in lactating cows fed a low- compared to a high-protein diet

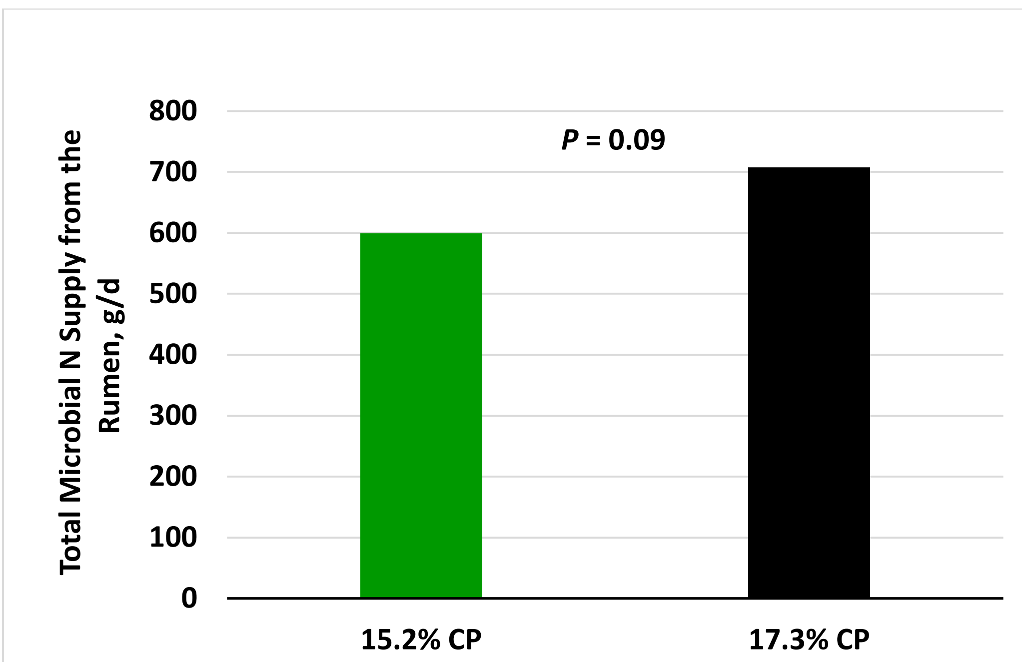


**Fig 2.** Microbial N flow out of the rumen in lactating cows fed a low- compared to a high-protein diet