Potential Use of Milk Urea Nitrogen to Abate Atmospheric Nitrogen Emissions from Wisconsin Dairy Farms

J. M. Powell,* C. A. Rotz, and M. A. Wattiaux

Urinary urea N (UUN) is the principal nitrogen (N) source controlling emissions of ammonia (NH₃) and nitrous oxide (N₂O) from dairy manure. The objectives of this study were (i) to study the integrative nature of dietary crude protein (CP) management, secretion of milk urea N (MUN), excretion of UUN, and N emissions from dairy production systems; (ii) to evaluate how associative changes in dietary CP, MUN, and UUN affect atmospheric N emissions from dairy farms; and (iii) to discuss some of the challenges and opportunities to an expanded use of MUN to enhance dietary CP use and decrease UUN excretion and N emissions from dairy farms. Milk urea N records of 37,889 cows in 197 herds in Wisconsin revealed that approximately one half of tested cows were likely consuming dietary CP in excess of requirement. Farm simulations were used to quantify the effect of dietary CP on whole-farm N emissions. At a statewide average MUN of 12.5 mg dL⁻¹, 48 to 87% of UUN was emitted as NH₃, with the lowest loss from pasture-based farms and the greatest loss from tie-stall farms. Each 1 mg dL⁻¹ decrease of MUN (range, 16–10 mg dL⁻¹) provided an associated daily decrease in UUN from 16.6 g per cow, which decreased NH₃ and N₂O emissions from manure by 7 to 12%. Although more site-specific information is required on herd MUN–UUN relationships and more a reliable interpretation of MUN assay results is needed, monitoring of MUN may be used to enhance dietary CP use and to reduce UUN excretion and N emissions from Wisconsin dairy farms.

Ammonia (NH₃), which dairy farms emit from barns, manure storage areas, and soils, can be hazardous to human and ecosystem health. Emission of NH₃ also contributes indirectly to nitrous oxide (N₂O) production, which is the most potent greenhouse gas emitted from agriculture (IPCC, 2006; Robertson et al., 2012). Most N₂O emissions from dairy farms occur directly from soils and manure storage areas, with negligible amounts emitted from most animal housing types (IPCC, 2006; Chianese et al., 2009).

Inefficiencies in N use and losses occur because livestock, crops, and other agricultural commodities are limited in their abilities to incorporate N into products (Sutton et al., 2013). For dairy cows, conversion efficiencies of dietary N into milk N range from 25 to 35%, with the highest efficiencies usually associated with high levels of milk production (Flachowsky and Lebien, 2006; Powell et al., 2006; Gourley et al., 2012). In a summary of 26 N balance studies of lactating dairy cows including 103 treatment means, Santos (2003) reported that N not secreted in milk is excreted on average approximately equally in urine (35% of total N intake; range, 13–51%) and feces (35% of total N intake; range, 26–52%).

Most feed N not secreted in milk is excreted approximately equally in feces and urine, although this ratio varies with the amount and form of feed N consumed (Broderick, 2003; Olmos Colmenero and Broderick, 2006b; Broderick et al., 2008). Also related to the amount and form of feed N consumed is the proportion of total urinary N (UN) that is urinary urea N (UUN). Marini and Van Amburgh (2005) reported that UUN increased from 23 to 96% of UN when dietary crude protein (CP) increased from 9 to 21% of dry matter (DM) intake. Ration balancing is considered a major pathway to reducing atmospheric N emissions from dairy farms (De Klein and Eckard, 2008; Powell et al., 2008; Aguerre et al., 2010).

General interactions between dietary N, milk urea N (MUN), UUN, and atmospheric N emissions from dairy farms are depicted in Fig. 1. In the rumen, the N-containing compounds are partially degraded, yielding ammonia-N as an end product, which may serve as an N source for the growth of...
protein-rich microbes, provided rumen fermentable energy is available. Undegraded dietary protein and microbial protein pass out of the rumen and are digested intestinally. Unused ruminal NH3–N and the NH3–N produced from gastrointestinal and hepatic tissue metabolism by deamination are detoxified into urea in the liver. Urea is then released to the general circulation as blood urea N. The urea in blood may be recycled back to the digestive system or excreted by the kidney as UUN. More balanced diets containing lower amounts of N can enhance the DNUE of dairy cows and can reduce UUN excretion and NH3 emissions, and these desired outcomes can be monitored using MUN (Powell et al., 2008; Burgos et al., 2010; Van Duinkerken et al., 2011). A recent analysis revealed that when MUN was reduced from 14 to 10 mg dL−1, NH3 emissions from dairy barns declined consistently by 10 to 34% (Powell et al., 2011). Although non-nutritional factors (e.g., breed, milking frequency) and laboratory technique can highly influence MUN (Wattiaux et al., 2005; Kohn et al., 2004; Spek et al., 2013), it has become an industry tool in the United States to fine-tune concentrations of dietary CP (N × 6.25) and energy in dairy cow rations.

The purpose of the present study is to highlight the integrative nature of dietary N management, the secretion of urea in milk, the excretion of urea in urine, and emissions of N from dairy production systems (Fig. 1). Using Wisconsin dairy farms as an example, our objectives were (i) to evaluate how associative changes in dietary CP, MUN, and UUN may affect NH3 and N2O emissions from barns, manure storage, and land components of commercial dairy farms; (ii) to determine how reductions in MUN and UUN may lead to statewide reductions in NH3 and N2O emissions from dairy manure; and (iii) to discuss some of the challenges and opportunities to an expanded use of MUN to enhance DNUE and decrease UUN excretion and N emissions from dairy farms.

**Materials and Methods**

Milk urea N distribution among cows in Wisconsin dairy herds over 2 yr (2010–11) was obtained by randomly extracting 37,889 test-day records from 197 herds from the database of AgSource, Cooperative Resource International (a provider of Dairy Herd Improvement services). Also, data from five nutrition trials with lactating cows in Wisconsin (18 dietary treatments comprised mostly of alfalfa silage, corn silage, corn grain, protein supplements, and other minor ingredients fed as total mixed rations to 203 mid-lactation cows) were used in a mixed model (SAS Institute, 2010) to determine relationships between dietary CP, MUN, and UUN excretion. In this model, the five nutrition trials were designated as random variables to account for the variance associated with these trials (St-Pierre, 2001).
The Integrated Farm System Model (IFSM) (USDA, 2012) was used to estimate NH₃ and N₂O emissions from typical dairy production systems in Wisconsin as a function of dietary CP and the resulting UUN excretion. The IFSM is a research tool used to assess the environmental and economic sustainability of farming systems. Animal production, feed storage and use, manure handling, crop production, and harvest are simulated on a daily time step over 25 yr of weather (Rotz et al., 2012). Nutrient requirements for each animal group on the farm are determined using the Cornell Net Carbohydrate and Protein System as documented by Fox et al. (2004). Diets are formulated to minimize dietary CP intake while meeting degradable and undegradable protein requirements with the available feeds (Rotz et al., 2012).

In IFSM, the quantity and nutrient contents of the manure produced are a function of the feeds consumed and herd characteristics (Rotz et al., 2012). Nutrient flows are tracked through the farm to predict losses to the environment and potential accumulation in the soil. Process-level simulation is used in IFSM to predict NH₃ emissions from the barn, manure storage, field-applied manure, and deposits of grazing animals. Nitrous oxide emissions are also estimated from crop and pasture land. Emission processes of compound formation, diffusion, and volatilization are simulated on an hourly basis over each day of each year as influenced by manure and environmental conditions (Rotz et al., 2013). Emission factors based on the guidelines of the International Panel on Climate Change (IPCC, 2006) are used to predict daily N₂O loss from stored manure as a function of N concentration in the manure and the exposed surface area.

Five farms were simulated to represent the typical dairy farm types of Wisconsin (Table 1). For the pasture-based system, about 40% of the annual manure produced was deposited on pasture, and the other 60% was handled through daily hauling with application to cropland. The statewide distribution of dairy manure management systems represented the major manure management systems used in Wisconsin, and the portion of manure handled in each (Jackson-Smith et al., 1997; USDA, 2004; Powell et al., 2006; USEPA, 2011).

Each of the five farming systems was simulated over 25 yr of recent Madison, Wisconsin (43.1° N, 89.4° W) weather. Crops grown included alfalfa, grass, corn silage, and high-moisture corn grain. Farm-produced feeds were fed along with purchased soybean meal and a less degradable protein feed mix (58.0% CP containing 42.5% degradable protein and a net energy lactation of 1.85 Mcal kg⁻¹). Each farm fed, milked, and handled the manure of 100 Holstein cows producing 9080 kg yr⁻¹ of milk, about 40% of the annual manure produced was deposited on pasture, and the other 60% was handled through daily hauling with application to cropland. The statewide distribution of dairy manure management systems represented the major manure management systems used in Wisconsin, and the portion of manure handled in each (Jackson-Smith et al., 1997; USDA, 2004; Powell et al., 2006; USEPA, 2011).

Table 1. Dairy production systems commonly found in Wisconsin that were simulated with the Integrated Farm System Model.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Barn type</th>
<th>Manure collection</th>
<th>Manure storage</th>
<th>Manure incorporation</th>
<th>Grazing</th>
<th>Statewide distribution† %</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-1</td>
<td>free stall</td>
<td>scraped</td>
<td>slurry tank</td>
<td>2 d</td>
<td>no</td>
<td>32</td>
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<tr>
<td>FS-2</td>
<td>free stall</td>
<td>flushed</td>
<td>lagoon</td>
<td>2 d</td>
<td>no</td>
<td>17</td>
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<tr>
<td>TS-1</td>
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<td>gutter</td>
<td>daily haul</td>
<td>none</td>
<td>no</td>
<td>15</td>
</tr>
<tr>
<td>TS-2</td>
<td>tie stall</td>
<td>gutter</td>
<td>stack</td>
<td>2 d</td>
<td>no</td>
<td>24</td>
</tr>
<tr>
<td>PST</td>
<td>tie stall</td>
<td>gutter</td>
<td>daily haul</td>
<td>none</td>
<td>yes</td>
<td>12</td>
</tr>
</tbody>
</table>

† The major manure management systems used in Wisconsin and the estimated portion of total manure N handled in each system were estimated from Jackson-Smith et al. (1997), USDA (2004), Powell et al. (2006), and USEPA (2011).
throughout the Midwest (Wattiaux et al., 2005) and to bulk tank measurements of MUN on commercial dairy farms in Wisconsin ($n = 12$ herds) (Gourley et al., 2012) and Maryland ($n = 472$ herds) (Kohn, 2007). The average MUN of the surveyed cows in the present study was 12.5 mg dL$, which corresponds closely to the average MUN level of 12.0 mg dL$ on representative dairy farms in Wisconsin (54 herds, 4376 cows) (Powell et al., 2006) and to the average MUN value of 12.7 mg dL$ determined in the aforementioned larger-scale Midwest study (Wattiaux et al., 2005) and in the Maryland study (Kohn, 2007).

The mixed model revealed no significant interactions between the random variable nutrition trial and the fixed variables of dietary CP, MUN, and UUN. Dietary CP can be used therefore to accurately predict MUN and UUN ($R^2 = 0.89$ and 0.88, respectively), and MUN can be used to accurately predict UUN ($R^2 = 0.84$) (Fig. 2). In contrast to a recent review of factors influencing MUN and its relationship to UUN (Spek et al., 2013), the inclusion of both dietary CP and MUN in the present analysis as independent variables into the mixed model did not significantly improve predictions of UUN excretion. The change in MUN of 1.6 mg dL$ for each percent change in dietary CP (Fig. 2) was slightly lower than the 1.7 mg dL$ reported by Nousiainen et al. (2004) but greater than the 1.1 mg dL$ determined by Aguilar et al. (2012). The highly significant positive relationships between dietary CP and MUN and between MUN and UUN (Fig. 2) suggest that UUN excretion and the subsequent N emissions (Fig. 1) may be reduced substantially by feeding the lowest amount and the most appropriate type of CP to meet animal nutritional requirements. The analysis offered in the present study revealed that a reduction in dietary CP of about 0.6% units would reduce MUN by 1.0 mg dL$ and UUN by 16.6 g per cow per day (Fig. 2).

Simulation of the five farm systems at the statewide average MUN of 12.5 mg dL$ (Fig. 3) revealed that the lowest N emissions (52% of UUN) were from pasture-based dairy farms due to UUN conservation via direct deposition of urine in pasture. The greatest N emissions (80–89% of UUN) were associated with farms that use tie-stall barns with daily hauling of manure due to late or no field incorporation of manure. For farms with free-stall barns, the greatest NH$ loss occurred during land application (42–50% of total NH$ loss) or from barns (30–35% of total NH$ loss). High NH$ loss from free-stall barns is due to greater surface exposure of urine and continuous mixing of feces and urine by animals and scrapers during manure removal. For N$_2$O, the highest emissions occurred from slurry manure–based and pasture-based systems, followed by the systems that used daily hauling or lagoon storage. For the daily haul and lagoon storage systems, most N$_2$O emissions (42–85% of total N$_2$O loss) occurred from soils after manure application. For pasture-based dairy systems, about two thirds of N$_2$O emissions occurred from the dung (feces) and urine deposited directly in pastures during grazing.

Further simulations were done for each production system using UUN excretions associated with the dietary CP concentrations of 14.5 to 19.5% and MUN levels of 8 to 16 mg dL$. Predicted NH$ and N$_2$O emissions essentially declined linearly as MUN (and associated UUN excretion) declined. Assuming that the aforementioned frequency distribution of MUN reflects the distribution of MUN within each of the five types of dairy production systems (Table 1), each 1.0 mg dL$ reduction in field incorporation of manure. For farms with free-stall barns, the greatest NH$ loss occurred during land application (42–50% of total NH$ loss) or from barns (30–35% of total NH$ loss). High NH$ loss from free-stall barns is due to greater surface exposure of urine and continuous mixing of feces and urine by animals and scrapers during manure removal. For N$_2$O, the highest emissions occurred from slurry manure–based and pasture-based systems, followed by the systems that used daily hauling or lagoon storage. For the daily haul and lagoon storage systems, most N$_2$O emissions (42–85% of total N$_2$O loss) occurred from soils after manure application. For pasture-based dairy systems, about two thirds of N$_2$O emissions occurred from the dung (feces) and urine deposited directly in pastures during grazing.

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![Fig. 2. Relationship between dietary crude protein (CP), milk urea N (MUN), and urinary urea N (UUN) excretion for cows fed common rations on Wisconsin dairy farms. Data compiled from five nutrition trials comprising 18 dietary CP treatments fed to approximately 203 cows in Wisconsin (Broderick, 2003; Olmos Colomenero and Broderick, 2006a, 2006b; Broderick et al., 2008; Broderick et al., 2009). Each data point represents a dietary CP level–MUN–UUN treatment mean.](image)

![Fig. 3. Daily losses of urinary urea N (UUN; excreted at a corresponding statewide average milk urea N of 12.5 mg dL$) as NH$ and N$_2$O in the barn, manure storage, land application, and pasture components of five dairy farm systems (see Table 1 for a description of farm types) in Wisconsin. Total UUN losses (as percentage of UUN excreted) are provided above each bar.](image)
MUN would reduce statewide NH$_3$ emissions by about 12 g N per cow per day and would reduce N$_2$O emissions by about 0.5 g N per cow per day (Fig. 4). Therefore, each MUN decrease of 1 mg dL$^{-1}$ (within the range of 16–10 mg dL$^{-1}$) can be associated with decreases in NH$_3$ emission of 7.2 to 11.3% and N$_2$O emissions of 6.8 to 12.2%. On a statewide basis, reductions in MUN within the range of 16 to 10 mg dL$^{-1}$ would reduce NH$_3$ emissions by approximately 29 to 43% (which are weighted mean reductions based on proportion of farm types in Wisconsin listed in Table 1) and N$_2$O emissions by 15 to 22% (assuming equal amounts of N$_2$O are derived from manure, and the sum of all other N sources, such as fertilizer N, soil organic N, legume-fixed N).

**Discussion**

To depict farming system differences (Fig. 3), N emissions from the barn, manure storage, and land application components of five dairy farm types were estimated using the UUN excretion (171 g per cow per day) estimated from the statewide average MUN value of 12.5 mg dL$^{-1}$ (Fig. 2). To illustrate dietary CP impacts, N emissions on a whole-farm basis were estimated from the UUN excretions associated with the observed range of MUN found on Wisconsin dairy farms (Fig. 4). These latter simulations encompassed a 2-fold difference in UUN excretion ($\sim$110–220 g per cow per day) (Fig. 2) at an annual barn temperature range of 6.5 to 9.5°C (25-yr mean, 7.7°C).

The NH$_3$ emitted from free-stall barns in Wisconsin was estimated to be 30 to 35% of UUN (Fig. 3). Across a threefold difference in UUN applications to simulated free-stall barn floors at a constant warmer temperature (25°C), a higher but similarly narrow range of 41 to 47% of UUN was emitted as NH$_3$ (Misselbrook et al., 2005). These results suggest that N emission may be predicted across a wide range of UUN excretion rates and environments using process models based on scientific principles (Rotz et al., 2013).

The first task in reducing N emissions from dairy farms is to encourage more targeted protein feeding practices. The MUN assay was developed to enhance feed protein use. More targeted protein feeding would enhance DNUE and would reduce UUN excretion and therefore N emissions from dairy farms. For example, Powell et al. (2006) determined that approximately one half of the dairy farms in Wisconsin feed multiple, balanced rations to cows that are grouped based on milk production, and these farms obtained significantly higher DNUE than farms that feed a single ration to all lactating cows. Also, producers who managed large herds analyzed forages and balanced rations and as a result obtained higher DNUE than farmers who managed small herds without following these practices. On many dairy farms, particularly farms managing smaller herds, more strategic feeding and ration balancing could substantially reduce the need for purchased protein or energy supplements, which would reduce annual feed costs by approximately $60 to $95 per cow (USDFRC, 2010). Additional savings (and reduced environmental impacts) may be accrued from the reduced need to grow high-protein crops as dairy cattle feed. For these reasons, the expanded use of MUN may lead to multiple economic and environmental benefits to producers and the environment.

There are other compelling reasons to pursue an expanded use of MUN as a dietary N refinement and N emission abatement tool: (i) dietary N–MUN–UUN relationships are based on sound scientific understanding of urea transformations (Fig. 1) in various components of dairy production systems, (ii) UUN is the principal source of N emissions from dairy manure, (iii) UUN can be predicted by MUN with relatively high accuracy ($R^2 = 0.84$) (Fig. 2), and (iv) systems are in place to provide MUN data to dairy producers and nutrition consultants at low cost. A more widespread, expanded use of MUN as a feed management and N emission abatement tool would require more site-specific information on animal physiological and dietary N management factors that affect dietary N–MUN–UUN relationships. Other requirements include accurate and reliable methods of MUN measurement and collaboration among stakeholders (e.g., producers, nutrition consultants, milk processors, and policymakers) to establish MUN benchmarks, targets, and possible economic incentives.

**Need for Site-Specific Information on Relationships between Dietary Crude Protein and Milk Urea N**

In addition to dietary factors, there are many animal and management factors that affect dietary CP–MUN–UUN relationships. For example, an analysis of 400,000 cow-level MUN records indicated significant effects on MUN of breed (Holstein vs. Jersey vs. Brown Swiss), parity (primiparous vs. multiparous cows), milk sample type (morning vs. evening sampling), milking frequency (two times vs. three times per day), and seasons (Wattiaux et al., 2005). A recent review also highlighted the impact of frequency of feeding and milking on MUN and its relation to UUN (Spek et al., 2013). Furthermore, there is evidence for genetic variation in MUN (Wood et al., 2003) and cows’ urea metabolism, which may lead to variation in MUN among herds independently of dietary recommendations (Aguilar et al., 2012). Thus, caution should be exercised to avoid recommending across-the-board reductions in dietary CP to achieve lower MUN without assessing farm-specific impacts of dietary CP on milk production and MUN and UUN excretion.

For most dairy cows, reducing dietary CP to recommended levels would enhance DNUE and reduce MUN and UUN without sacrificing milk production. For example, of the 18
dietary CP treatments (range, 14.8–19.4% DM) used in the five nutrition trials analyzed in the current study (Fig. 2), 16 reductions in dietary CP led to significant \( P < 0.05 \) reductions in MUN, 17 resulted in significant reductions in UUN, and only two resulted in significant reductions in milk production: (i) a reduction in dietary CP from 18.4 to 15.1% (achieved by reducing rolled high-moisture shelled corn and solvent-extracted soybean meal in the diet) decreased milk production by 1.1 kg per cow per day (Broderick, 2003), and (ii) the reduction in dietary CP from 17.3 or 16.1 to 14.8% (due to reductions of solvent-extracted soybean meal in the diet) decreased milk production by 1.9 kg per cow per day (Broderick et al., 2008).

Pasture-based dairy farms have more variable MUN and lower DNUE than confinement-based farms (Gourley et al., 2012; Powell et al., 2012; Totty et al., 2013). This is due to variability in determinations of pasture quality and intake. On pasture-based farms, the scope for using test-day MUN as a tactical (day-to-day) feed management tool may therefore be more challenging. Bulk-tank MUN levels, such as those analyzed for dairy farms in Maryland (Kohn, 2007) and Wisconsin (Gourley et al., 2012), may have application as an operational management tool (e.g., sward composition, type and amount of supplemental feed, and system designs that maximize overall N use efficiency and fertilizer N applications). For example, research on the effect of different sward compositions on MUN and UUN suggests that pastures containing diverse plant species result in lower MUN and UUN excretions compared with the more common ryegrass and white clover mixtures (Totty et al., 2013).

### Less Variable and Low-Cost Estimates of N Emission Using Milk Urea N

A large source of error in using MUN to predict UUN excretion and N emissions may be in obtaining an accurate and consistent measurement of MUN given the wide array of sampling protocols and measurement techniques. Variations in test-day MUN are highest on farms that manage low-producing cows (Rajala-Schultz and Saville, 2003) where single diets are often fed to all lactating cows (Powell et al., 2006). The lower variability in test-day MUN on farms that manage high-producing cows can be attributed in part to more consistent day-to-day management, feeding, and forage quality. These results suggest that multiple sources of variation need to be considered when interpreting test-day and bulk tank MUN data in the field.

In some locations, better quality control may be needed to increase the accuracy and repeatability of the MUN assays. For example, recoveries of known amounts of urea added to milk sent to commercial laboratories ranged from 47 to 95% among five analytical methods, and MUN concentrations also varied among laboratories using the same analytical method (Peterson et al., 2004). From an environmental perspective, MUN values based on rapid and inexpensive infrared assays have been found to accurately predict dietary N and UUN relationships with the same precision as the more time-consuming and expensive colorimetric and enzymatic assays (Broderick, 2003). The infrared MUN assay may therefore be well suited for use as an N emission abatement tool because it is already used widely throughout the U.S. dairy industry at relatively low cost.

### An Expanded Use of Milk Urea N Requires Collaboration

Further development of MUN for environmental use will require collaboration among key dairy industry stakeholders (e.g., researchers, dairy producers, and nutrition consultants) to better understand what, how, and why feed management decisions are made and how these factors may affect milk production and MUN, UUN, and N emissions. Milk processors and policymakers need to be included in the application of MUN as a N management tool. Economic incentives, such as price premiums for milk shipped within a desired range of MUN, may nudge the industry toward a decrease in undesirable N emissions. To accommodate for intrinsic variation in MUN associated with animal genetics or production systems, baseline and target MUN values may need to be established on a per herd basis (Wattiaux et al., 2005; Aguilar et al., 2012).

Some policymakers recognize that animal-based parameters, such as MUN, may provide good “proxy” indicators of environmental performance. For example, to assist livestock producers in their compliance to the Wisconsin’s Air Toxics Rule, the Wisconsin Department of Natural Resources proposed “Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste in Wisconsin” (Wisconsin DNR, 2010). “Standard practices” were established as “benchmarks” for calculating relative reductions in NH\(_3\) (and hydrogen sulfide) emissions due to the adoption of beneficial management practices.

To assess the impacts of beneficial feeding practices, a base MUN value of 14 mg dL\(^{-1}\) was selected as a common benchmark, a 10% NH\(_3\) emission reduction credit was given for farms having monthly average bulk-tank MUN concentrations of 12 to 14 mg dL\(^{-1}\), and a 20% reduction credit was given for farms that kept monthly MUN concentrations below 10 mg dL\(^{-1}\) (Wisconsin DNR, 2010).

### Conclusions

This study suggested that approximately one half of Wisconsin’s lactating dairy cows are likely fed dietary CP in excess of requirements. Using data from five nutrition trials that used diets commonly fed to Wisconsin dairy cows, highly significant positive relationships were observed between dietary N, MUN, UUN excretion and statewide N emissions. This implies that an expanded use of MUN as a N management tool may not only enhance dietary N use efficiency and reduce milk production costs but also may reduce the negative impacts associated with increases in UUN excretion and the resulting N emissions. Within the range of 16 to 10 mg dL\(^{-1}\), each MUN reduction of 1 mg dL\(^{-1}\) leads to a UUN excretion decrease of 16.6 g per cow per day, which results in NH\(_3\) and N\(_2\)O reductions of approximately 7 to 12%. The extension of MUN as a multipurpose N management tool requires site-specific, herd-level information on dietary CP and MUN relationships to set baselines and targets for desired MUN levels. Standardization of MUN sampling protocols and dependable assays are also required to reduce the variability and enhance the repeatability of MUN analyses. With accurate and repeatable measurements and realistic targets, the dairy industry may be willing to adopt an incentive structure whereby premiums are offered for milk produced and shipped within a desired range of MUN values. This would offer a relatively straightforward and practical way to move the industry in a positive, cost-effective direction toward abatement of NH\(_3\) and N\(_2\)O emissions.
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