Ammonia Loss and Fertilizer Nitrogen Recovery from Surface-Applied Urea during the Overwinter Months

By Richard Engel, Carlos Romero, Clain Jones, and Tom Jensen

Montana's semiarid climate contributes to greater susceptibility of surface applied urea to ammonia (NH_3) loss overwinter.
Instead of late-fall or winter applications, a spring application of urea after soils have thawed provides the greatest agronomic and environmental benefits.

Broadcast applications of urea during the overwinter period is a common management practice for dryland winter wheat production in semi-arid Montana. The popularity of this practice is based on the need to spread workloads. Farms in this region commonly have > 1,000 ha under no-till or minimal tillage systems and this places considerable pressure on farmers to complete planting operations over a short-time span (e.g., < 2 weeks in mid-September).

Surface applications of urea are widely recognized as being susceptible to NH_3 loss. However, the long-held belief by farmers and their fertilizer suppliers is that NH_3 loss can be mitigated, or prevented, by applying urea to cold soils during the overwinter period. Our research has shown that is not necessarily the case (Engel et al., 2012), and that considerable loss of N as NH_3 (i.e., > 20% of the applied amount) can occur following urea application to cold soils with temperatures < 5°C, including soils covered with a modest snowpack. The most important finding of this research is that the worst-case conditions for NH_3 loss were after urea applications were made to moist soil surfaces with high moisture content, followed by slow drying with little or no precipitation. In Montana and other neighboring areas of the Northern Great Plains, these conditions are more likely to occur during the overwinter period compared with the spring. Soil surfaces are usually frozen during the winter, but still can be moist due to intermittent periods of shallow surface thawing. The distribution of precipitation is such that winters are typically dry with only 14 to 15% of the total annual precipitation (310 to 420 mm) occurring over a 4-month period (Dec 1 to Mar 31; MCO-UM, 2015). As a result, precipitation events will typically be low in volume, and broadcast urea applied to the soils is likely to remain near the surface where it is susceptible to volatilization. Conversely, in the spring following thaw, temperatures are warmer and drying of the soil surface is more rapid. Spring precipitation events that occur tend to be larger in volume and surface-applied urea will more likely be dissolved and infiltrate further into the soil where it is less susceptible to volatile losses.

The apparent difference in susceptibility of urea to volatilization between overwinter and early-spring applications timings prompted us to examine more closely the cumulative NH_3 losses during these periods. Also, treating urea with urease inhibitor (NBPT) is a recognized method to reduce NH_3 losses from surface-applied urea applications (Engel et al., 2011; Grant et al., 1996; Sanz-Cobena et al., 2008; Turner et al., 2010). Hence, we compared NH_3 losses from urea with and without this fertilizer additive.

Abbreviations and notes: N = nitrogen; NH_3 = ammonia; NBPT = N-(n-butyl) thiophosphoric triamide. IPNI Project USA-MT17

Ammonia measurements were quantified by a micrometeorological approach that utilized circular plots (40 m dia), and a center mast equipped with samplers for collecting NH_3. These measurements were coupled with a companion study run at the same field site, where fertilizer N recovery by winter wheat was quantified using ^{15}N-enriched urea applied to micro-plots within a replicated small-plot experiment design. We hypothesized that: i) cumulative NH_3 loss from urea would be greater for late-fall and winter applications, or overwinter applications, relative to the spring application timings, ii) addition of NBPT would reduce NH_3 loss from urea, and iii) cumulative fertilizer NH_3 loss would ultimately affect fertilizer N recovery by winter wheat.

Field Experiments

Field trials were conducted at private farms in central Montana during the 2011/12, 2012/13, and 2013/14 seasons. The experiments were located in large fields (> 60 ha) that were under a no-till, crop-fallow management system with winter wheat being the dominant crop. The micrometeorological experiments and replicated small-plot experiments with ^{15}N-labelled urea were conducted at the same time but at physically separated locations within the farm fields. The trials consisted of three fertilization application timings (late-fall, winter, and spring) and two N sources (urea and urea+NBPT). The first application event or timing (late-fall) was made in late-November to early-December at approximate soil freeze-up. The second event (winter) was applied in February to frozen soil. The third event (spring) was applied in April following ground thaw and crop green-up. Urea and urea+NBPT were applied at a rate of 100 kg N/ha. The urea was coated with NPBT (1 g/kg) as a liquid formulation sold under the trade name, Agrotain Ultra™ (Koch Agronomic Services, LLC, Wichita, KS, USA).

NH_3 Flux vs. Time Relationships

Ammonia flux measurements revealed very different patterns of NH_3 loss following urea applications in the overwinter period (late-fall and winter) compared to the spring (**Figure 1**). In all years, NH_3 flux following the late-fall and winter applications rose over 14 to 58 d to peaks that were higher than for the spring application timings. Thereafter, NH_3 emission activity was prolonged and did not fall to nominal levels (≤ 3 g N/ha/h) until 87 to 103 d and 49 to 62 d post-fertilization for these respective application timings. The prolonged emission activity was in part a result of the cold temperatures and dry conditions that slowed or limited urease activity. Also, the soil below the surface was largely frozen and any precipitation and melting of snow that occurred did not allow for urea infiltration

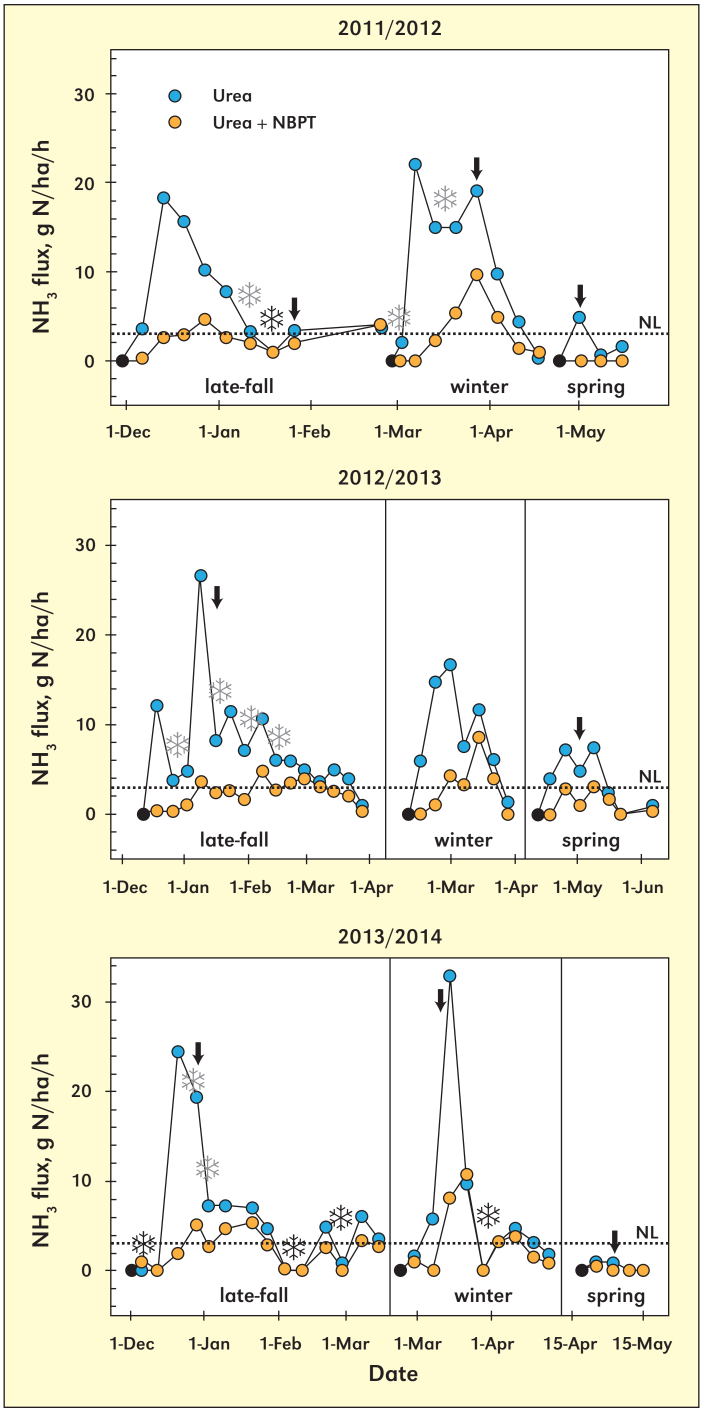

Figure 1. Ammonia from urea and urea coated with *N*-(*n*-butyl) thiophosphoric triamide (NBPT) following three application timings (late-fall, winter, spring) during 2011/2012, 2012/2013 and 2013/2014. Dark circles indicate the fertilizer application dates (NH_3 flux is assumed = 0). Arrows indicate proximate time when 95% of applied urea (without NBPT) had hydrolyzed. NL = nominal level (3 g N/ha/hr). ❄, ❄ Indicate partial and full snow cover, respectively.

Figure 2. Time sequence photographs of field site. NH_3 emission activity was effectively blocked by the snow cover on received on Dec 22 (top), then resumed following the melting of the snow cover over 2-week period (**see Figure 1**)

into the soil to a depth where it was protected against volatilization to the atmosphere. The pattern of NH_3 emission activity following the late-fall and winter urea applications sometimes exhibited a deep saw-tooth, or up and down, pattern as a result of intermittent snow cover and wet-dry cycles (**Figure 2**). For example, the drop-off in NH_3 flux at the second (Dec 26) and third (Jan 2) sampling events of the late-fall 2012/13 trial was a result of two light snowfall events (5 and 2.5-cm depth) that occurred 10 d (Dec 22) and 21 d (Jan 2) postfertilization. These snowfall events effectively blocked NH_3 release to the atmosphere.

The accumulated snow then melted and NH_3 emission flux resumed as evident by the peak on Jan 9 (**Figure 2**). In all years, NH_3 flux following the spring applications were lower in

Table 1. Cumulative NH_3 loss (% applied N) from urea and urea+NBPT for late-fall, winter, and spring applications. Average over three years (2011/12, 2012/13, 2013/14).

	-------- N fertilizer source --------	
	Urea	Urea + NBPT
Application timing	----------- % applied -----------	
late-fall	16.4 a†	6.0 c
winter	11.4 b	4.2 c
spring	2.0 cd	0.6 d

† timing x N source significant (p = 0.003) and means followed by the same letter are not significantly different (p = 0.05).

TAKE IT TO THE FIELD

Delay urea application until after the spring thaw when larger precipitation events can move N down into the soil where it is more protected from volatilization.

Use of NBPT will reduce NH_3 loss from surface applied urea—by up to two-thirds compared to untreated urea.

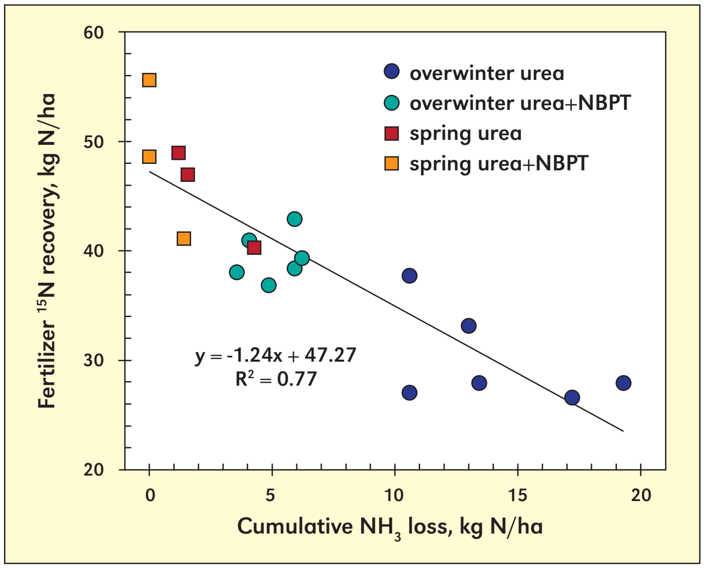

Figure 3. Fertilizer-^{15}N recovery in grain plus straw of winter wheat and cumulative NH_3 loss relationships among the N management strategies that included urea and urea+NBPT (100 kg N/ha) applied during the overwinter period (late-fall, winter) and spring following thaw. Three-year summary (2011/12, 2012/13, 2013/14) from central Montana.

intensity and shorter in duration than the late-fall and winter applications. Spring applications were made after the soils had thawed and precipitation events that occurred allowed for the greater depth infiltration of urea. Also, the precipitation events were larger during the spring compared to the overwinter period. For example, precipitation events during the spring often exceeded 12 mm, while during the late-fall and winter trial events were typically limited to snowfall with less than 6 mm water equivalent.

Ammonia flux versus time profiles for urea+NBPT indicate the urease inhibitor was effective in reducing NH_3 emissions, and the peak NH_3 flux observed for the three application timings. The mitigation effects were most clearly evident in the profiles for the late-fall and winter trials. Initially, NH_3 flux was reduced by 90 to 95% by NBPT over the first week following the dissolution of the fertilizer granules. Thereafter, the efficacy of NBPT diminished such that the NH_3 flux vs. time curves for urea and urea+NBPT converge at 50 to 75 d and 28 to 48 d post-fertilization for the late-fall and winter applications, respectively (**Figure 1**).

Cumulative NH_3 Loss and Fertilizer N Recovery

A three-year summary of our results found cumulative NH_3 loss (% applied N) was significantly affected by timing and the interaction of timing and NBPT (**Table 1**). The interaction resulted because the mitigation of cumulative NH_3 loss by NBPT was greater for the overwinter urea applications relative to the spring urea applications. Multiple comparison tests show the largest cumulative NH_3 loss was observed for urea applications in the late-fall followed by the winter applications. Cumulative NH_3 was similar between the urea+NBPT late-fall and urea+NBPT winter applications. The addition of NBPT reduced cumulative NH_3 loss from urea by 63.4, 63.2, and 70.0% for the late-fall, winter, and spring applications, respectively.

Our measurements of fertilizer ^{15}N recovery of urea in the grain plus straw at maturity were directly related to cumulative NH_3 loss at the field sites (**Figure 3**). The high correlation (R^2=0.77) indicates that volatilization represents an important pathway for N loss in semiarid climates when urea is surface-applied during the overwinter period. This was further validated by our finding that the addition of NBPT improved wheat fertilizer ^{15}N recovery of urea, in particular for the late-fall and winter application timings.

Summary

This three-year study supported our hypothesis that cumulative NH_3 loss following overwinter (Dec to Mar) applications of urea would be larger than spring applications following thaw. There are a number of environmental factors in Montana's semiarid climate that likely contribute to the greater susceptibility of urea to NH_3 loss during the overwinter period. Precipitation events following the late-fall and winter applications of urea were typically small in size (≤ 6 mm) and most often occurred as light snowfall events, hence urea likely remained at, or near, the surface for a prolonged time. Also, frost layers in the soil prevented the downward movement of water and dissolved urea. In contrast, precipitation following the spring applications often consisted of larger events (≥ 12 mm) that reduced NH_3 emission activity. In general, the pattern of low intensity and small precipitation events during the late-fall and winter versus larger precipitation events during the spring is consistent with long-term records of climate in the semiarid northern Great Plains. Finally, the management implications of this study are that late-fall and winter urea applications should be avoided to provide the greatest benefit to soil N fertility, and to minimize NH_3 emissions into the atmosphere. Addition of NBPT (1 g/kg) will reduce cumulative NH_3 loss from urea by approximately two-thirds over untreated urea. However, the best management strategy is to delay urea applications until the spring after soils have thawed, and when larger precipitation events are more likely to occur that allow for urea-N infiltration into the soil where it is protected against volatilization to the atmosphere. BC

The mention of any trade name does not necessarily imply any endorsement.

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Dr. Tai McClellan Maaz Named IPNI Nitrogen Program Director

Dr. Tai McClellan Maaz has been hired as Nitrogen Program Director with the International Plant Nutrition Institute (IPNI) effective September 1, 2017. Dr. Maaz will be based from IPNI Headquarters in Peachtree Corners, Georgia, USA.

Prior to Dr. Maaz's appointment to IPNI, she held a United States Department of Agriculture (USDA) Agriculture and Food Research Initiative (AFRI) Post-doctoral Fellowship at Washington State University in Pullman, Washington. Dr. Maaz's recent post-doctoral fellowship and concurrent research has been focused on the management of nitrogen to minimize losses and improve use within cereal-based agronomic systems including the dryland winter wheat grown in the Palouse region of the northwestern U.S. Dr. Maaz's Ph.D. research led to recommended economic optimal nitrogen rates for canola in Eastern Washington. She also examined the impact of nitrogen supply, available water, and rotational effects on nitrogen use efficiency. Dr. Maaz succeeds Dr. Clifford Snyder who retired from the position of Nitrogen Program Director since 2007.

"We express our gratitude to Dr. Snyder for the significant impact he has had over his 22-year career with IPNI. The skills and experience that Dr. Maaz brings to the Institute will position her well as she takes over the role and we look forward to her Directorship," said Dr. Terry Roberts, President of IPNI.

Dr. Tai McClellan Maaz
IPNI Nitrogen Program Director

Tai received her Ph.D. from Washington State University (Soil Science) in 2014, her M.Sc. from the University of Hawaii in 2010, and her B.Sc. from the University of Hawaii in 2007. As a Ph.D. student, she received training in the National Science Foundation (NSF) Integrated Graduate Education Research Training (IGERT)'s Nitrogen Systems: Policy-oriented Integrated Research and Education (NSPIRE) program. She presently belongs to the Soil Science Society of America, the American Society of Agronomy, as well as the Center for Environmental Research, Education and Outreach at Washington State University.

Dr. Tom Bruulsema Named IPNI Vice President, Americas & Research

Dr. Tom Bruulsema of Guelph, Ontario, Canada has been promoted to Vice President, Americas & Research, with the International Plant Nutrition Institute (IPNI) effective June 26, 2017.

Prior to Dr. Bruulsema's appointment to IPNI Vice President, he has served as IPNI Phosphorus Program Director since 2015. Dr. Bruulsema has also served as Northeast Regional Director for the IPNI North America Program since the Institute's establishment in 2007, which is a position he also held for PPI since 1994. Dr. Bruulsema succeeds Dr. Paul Fixen who retired from IPNI after an impactful 28-year career.

"Paul will be missed, but the knowledge and experience Dr. Bruulsema brings to his new role will ensure a smooth transition for our Institute," said Dr. Terry Roberts, President of IPNI.

A native of Guelph, Ontario, Dr. Bruulsema received his B.Sc. (Agriculture) at the University of Guelph, Ontario, his M.Sc. (Crop Science) at the University of Guelph, and his Ph.D. (Soil Science) at Cornell University, New York. Prior to his work with the Institute, Dr. Bruulsema worked as a research associate at the University of Minnesota (1994) and an agronomist with the Mennonite Central Committee in Bangladesh (1986-1990).

Dr. Tom Bruulsema
IPNI Vice President, Americas & Research

Throughout his 23-year career with the Institute, Dr. Bruulsema has been a respected leader for agronomic research and education programs in North America and beyond. Dr. Bruulsema has been recognized as a Fellow of the American Society of Agronomy (ASA), the Soil Science Society of America (SSSA), and the Canadian Society of Agronomy, and is a Certified Crop Adviser.