**BACKGROUND INFORMATION AND RESEARCH PROBLEM**

Soft red winter wheat (*Triticum aestivum* L.) requires adequate nitrogen (N) fertilization to produce maximal yields on most soils. Nitrogen fertilizer is usually applied to wheat in February just after tillering and prior to early spring growth. Typical recommendations include applying 90 lb N/acre in a single application on well-drained, silt-loam soils in mid-February to mid-March, however, higher N rates or poorly drained soils may require split applications. Urea is typically applied and is more susceptible to NH$_3$ volatilization than some other N fertilizers. Ammonia volatilization can cause economic loss to farmers applying urea fertilizer by reducing fertilizer use efficiency, as well as contribute to environmental problems (e.g., eutrophication). Ammonia loss occurs when surface-applied urea undergoes hydrolysis and is converted to NH$_3$ by the urease enzyme, and microsite pH near the urea prill is drastically increased thereby preventing conversion to NH$_4^+$. Despite a lower risk of volatilization losses in winter wheat compared to summer-grown crops, warm and wet conditions during early spring in Arkansas can be favorable for urea-N losses via volatilization. Engel et al. (2011) reported NH$_3$ losses on cold temperature soils were highly variable and could range from 3% to 44%. Other research reports NH$_3$ losses from surface-applied urea were highly variable based on soil texture, fertilizer application timing, cultural management, and environmental conditions and could range from negligible to over 50% (Sommer et al., 2004; Turner et al., 2010). Soil moisture was also implicated as a more influential climatic factor than warm temperatures. In an effort to increase producer profitability and improve fertilizer use efficiency on wheat, implementation of nutrient management practices that reduce the risk of N loss from surface-applied urea may be warranted.

One additive that can be used to reduce NH$_3$ volatilization loss from urea (e.g., under conditions that include high soil moisture, warm temperature, wind, etc.) is the urease inhibitor N-(n-butyl)-thiophosphoric triamide (NBPT), sold under the trade name Agrotain (Agrotain International, St. Louis, Mo.). Slaton et al. (2011) reported variability in the agronomic, and hence economic, benefits of applying Agrotain-treated urea to winter wheat due presumably to variable soil and weather conditions present when urea-N was applied. Their results indicated that additional research was needed to clarify the conditions under which NH$_3$ loss from urea occurs during February and March. Our research objectives were to examine differences, if any, in grain yield, total dry matter (TDM), and N uptake by soft red winter wheat fertilized with urea, urea+NBPT, or (NH$_4$)$_2$SO$_4$ applied at three N rates (40, 80, or 120 lb N/acre) and to compare NH$_3$ volatilization from the three N sources applied at 120 lb N/acre.

**PROCEDURES**

A fertilization experiment was initiated during the fall 2010 to evaluate the effect of N fertilizer rate and source on wheat TDM$_3$, yield, and NH$_3$ volatilization. The trial was established on a Captina (Typic Fragiudult) silt loam following summer fallow at the Arkansas Agricultural Research and Extension Center located in Fayetteville, Ark. Five composite soil samples (0- to 4-in. depth) were taken from the site to determine soil chemical properties. Soil was oven-dried, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, total N and C, inorganic N (NO$_3^-$-N and NH$_4^+$-N), and soil water pH. The mean chemical values for this soil were 7.2 pH, 0.10% total N, 0.97% total C, 12.5 ppm NO$_3^-$-N, 9.9 ppm NH$_4^+$-N, 39 ppm P, 156 ppm K, 1317 ppm Ca, 52 ppm Mg, 12 ppm S, 98 ppm Fe, 232 ppm Mn, 3.0 ppm Zn, 3.5 ppm Cu, and 0.14 ppm B. AgriPro ‘Beretta’ wheat was drill-seeded (120 lb seed/acre) into a conventionally tilled seedbed on 15 October. Plots were 20-ft long by 8-ft wide allowing for twelve rows of wheat with a 7-in. row spacing.

Fertilizer treatments were broadcast by hand to each plot once on 22 February after wheat had begun to tiller (Feekes stage 3). Nitrogen sources included urea, urea treated with NBPT, and (NH$_4$)$_2$SO$_4$ (21-0-0-24S) sold under the trade name Honeywell Sulf-N® Ammonium Sulfate (Honeywell, Morristown, N.J.) with each source applied at 0, 40, 80, and 120 lb N/acre. Potassium (100 lb muriate of potash/acre) and phosphorus (100 lb triple superphosphate/acre) were broadcast applied to the area in late January to ensure these nutrients were not yield-limiting factors. Wheat was sampled for dry matter at heading (20 April, Feekes 10.5) by cutting three feet of an interior row. At maturity (13 June), grain yield was measured by harvesting eleven rows of wheat using a plot combine. Grain yield was adjusted to the uniform moisture of 13%.
The experiment was a three-by-three factorial design with three replicates for each treatment defined by three N sources by three N rates compared to a no N control. Analysis of variance was conducted using PROC GLM in SAS v9.2 (SAS Institute, Inc., Cary, N.C). Mean separations were evaluated using Fisher’s Protected Least Significant Difference method at significance level 0.10.

A semi-open, static chamber system was used to measure NH emissions from each fertilizer source applied at 120 lb N/acre as described by Griggs et al. (2007). Clear acrylic tubes measuring 5.5 in. (inside diameter) × 30 in. (height) were placed over actively growing wheat plants and driven 6 in. into the soil surface to prevent air flux or water infiltration. Plastic buckets were suspended 2 in. above each chamber with PVC pipe to allow air circulation, but prevent precipitation interference. Foam sorbers (1-in. thick) were formed cut to fit inside each chamber, washed with phosphoric acid, rinsed with deionized water, and stored in 1 gal plastic bags. Twenty mL of a 0.73 M H₃PO₄-33% glycerol (v:v) solution was added to each sorber to act as an acid trap for NH₃. The first sorber was placed approximately 6 in. below the top of the chamber to trap volatilized NH₃ from the fertilizer, and the second placed flush with the top of the chamber to limit interference from atmospheric NH₃. Air temperature within and outside the chamber was measured using Onset StowAway Tidbit temperature sensors (Onset Computer Corp., Bourne, Mass.), suspended approximately 5 in. above the growing point of the wheat. Temperature data was logged every half-hour for the duration of the experiment.

The NH₃ volatilization experiment was started 22 February. Sorbers were sampled 3, 6, 9, 12, 15, and 18 days after N fertilizer was applied. Upon removal with laboratory tongs, sorbers were placed into their original plastic bags and returned to the laboratory for extraction. Extraction was conducted by adding 100 mL of 2 M KCl to each plastic bag containing a foam sorber and hand squeezing to ensure the foam was adequately saturated. After sitting in solution overnight, sorbers were again hand squeezed to separate the KCl solution from the foam, and a portion of the solution was collected in a scintillation vial. The concentration of NH₄-N was determined by an autoanalyzer (Skalar), and expressed as a percent of the total fertilizer N applied.

The experiment was a randomized complete block design with four replicates per treatment defined by four N sources including an untreated control and six sampling times. The experiment was analyzed as a split-plot design with N source as the whole plot and sampling time as the subplot. Analysis of variance was conducted using the PROC GLM function in SAS v9.2 (SAS Institute, Inc., Cary, N.C). Means separations were evaluated using Fisher’s Protected Least Significant Difference method at a significance level 0.10.

RESULTS AND DISCUSSION

Climatic conditions for the duration of the wheat study were atypical of a normal Arkansas winter. In general, temperatures were below normal during December through February with record cold occurring in December and February. These months were marked by six significant snow events with snow in excess of 18 in. occurring 9 February and temperatures reaching -18 ºF. April and May were marked by above normal rain and catastrophic flooding in northwest Arkansas, with 13.5 in. of rain falling over 7 days in April and 10 in. in May. These rains events resulted in 300% to 500% the normal precipitation for these months.

The main effect of N rate was the only significant variable for TDM, yield, or N uptake (Table 1). All N sources behaved similarly for each parameter and were always greater than the no N control (Table 2). Winter wheat showed a strong positive response to N rate when fertilized with 40 to 120 lb N/acre (Table 1). Yields increased incrementally with each increase in N rate. Grain yields were maximized by 120 lb N/acre. Total dry matter followed a similar trend as grain yield with TDM increasing numerically as N rate increased. However, these differences were not significant between 40 and 80 lb N/acre or 80 and 120 lb N/acre. All N sources, averaged across N rates, produced greater TDM than wheat fertilized with no N. Nitrogen uptake followed the same trend as grain yield with N uptake increasing significantly with each N rate and was maximized at 63 lb N/acre by 120 lb N/acre. Fertilizer recovery, calculated by the difference method, ranged from 36% to 39% for all N rates, averaged across N sources and was significantly lower than fertilizer use efficiency (46.7%) for soft red winter wheat reported by Bashir et al. (1997) using ¹⁵N-labeled urea.

The NH₃ volatilization experiment was conducted from 22 February to 13 March and temperature was recorded inside and outside of the volatilization chambers. Temperature inside the chamber ranged from 24 ºF to 117 ºF with an overall mean temperature of 54 ºF. Temperature and humidity data acquired from the National Climatic Data Center measured from Drake Field, Washington County, Ark., showed outside temperature ranged from 23 ºF to 72 ºF (mean 47 ºF) and humidity ranged from 22% to 100% (mean 72%). In general, mean temperature inside the chambers was 6.6 ºF warmer than the recorded outside air temperature.

Total NH₃ volatilization measured from 0 to 18 days after fertilization was relatively low with the maximum NH₃ evolved occurring for urea (2.6% of total N applied, Table 3). Urea+NBPT and (NH₄)₂SO₄ both produced NH₃-N loss of <1% of the total N applied. Cumulative NH₃ volatilization was significant for the source by day interaction. Across time, NH₃ volatilization from urea was always significantly greater than for urea+NBPT or (NH₄)₂SO₄. Ammonia volatilization from urea and urea+NBPT increased significantly from 0 to 9 days and 9 to 18 days with no significant NH₃ loss occurring after 12 days of the 18 day measurement period. Ammonia loss from (NH₄)₂SO₄ was never significant, reaching a maximum of only 0.16% of the applied N by 18 days after fertilization.

PRACTICAL APPLICATION

Nitrogen source had no significant effect on N uptake and grain yield by winter wheat, but both increased as N rate
increased from 0 to 120 lb N/acre. Significant growth and yield differences among N sources were not measured and are consistent with relatively low NH$_3$ volatilization loss from urea (<3% of the applied N) and the other N sources applied to the soil surface in late February. Under the conditions of this study, NH$_3$ volatilization loss was not a major source of N loss and there was no benefit from using (NH$_4$)$_2$SO$_4$ or Agrotain-treated urea compared to urea. Plant uptake and NH$_3$ loss, as measured in the chambers, accounted for about 40% of the applied N suggesting the remaining 60% of the applied N resided in plant roots, was immobilized, remained in the soil as inorganic N, or was lost via leaching, runoff, or denitrification. Future studies investigating NH$_3$ loss from surface-applied urea and the potential benefits of urease inhibitors should perhaps examine specific situations (e.g., soil moisture, frozen soils, air temperature, etc.) to better identify under what circumstances a urease inhibitor might be beneficial.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


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**Table 1. Winter wheat grain yield, total dry matter accumulation (TDM), and N uptake as affected by N fertilizer rate, averaged across N sources, at the Arkansas Agricultural Research and Extension Center during the 2010 to 2011 growing season.**

<table>
<thead>
<tr>
<th>N rate (lb N/acre)</th>
<th>Grain yield (bu/acre)</th>
<th>TDM (lb/acre)</th>
<th>N uptake (lb N/acre)</th>
<th>Fertilizer recovery (% of applied)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23</td>
<td>3688</td>
<td>20</td>
<td>---</td>
</tr>
<tr>
<td>40</td>
<td>38</td>
<td>5520</td>
<td>35</td>
<td>38</td>
</tr>
<tr>
<td>80</td>
<td>48</td>
<td>6152</td>
<td>51</td>
<td>39</td>
</tr>
<tr>
<td>120</td>
<td>53</td>
<td>6731</td>
<td>63</td>
<td>36</td>
</tr>
<tr>
<td>LSD (0.10)</td>
<td>3</td>
<td>728</td>
<td>3</td>
<td>---</td>
</tr>
<tr>
<td>$P$-value</td>
<td>&lt;0.0001</td>
<td>0.0306</td>
<td>&lt;0.0001</td>
<td>---</td>
</tr>
<tr>
<td>CV %</td>
<td>8.1</td>
<td>16.3</td>
<td>9.0</td>
<td>---</td>
</tr>
</tbody>
</table>
Table 2. Winter wheat grain yield, total dry matter accumulation (TDM), and N uptake as affected by N source, averaged across N rates, at the Arkansas Agricultural Research and Extension Center during the 2010-2011 growing season.

<table>
<thead>
<tr>
<th>N source</th>
<th>Grain yield (bu/acre)</th>
<th>TDM (lb/acre)</th>
<th>N uptake (lb/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>47</td>
<td>5993</td>
<td>48</td>
</tr>
<tr>
<td>NBPT-treated Urea</td>
<td>45</td>
<td>6300</td>
<td>51</td>
</tr>
<tr>
<td>(NH$_4$)$_2$SO$_4$</td>
<td>47</td>
<td>6111</td>
<td>50</td>
</tr>
<tr>
<td>UTC</td>
<td>23</td>
<td>3688</td>
<td>20</td>
</tr>
<tr>
<td>LSD (0.10)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>P-value</td>
<td>0.5951</td>
<td>0.4971</td>
<td>0.2006</td>
</tr>
<tr>
<td>CV %</td>
<td>8.1</td>
<td>16.3</td>
<td>9.0</td>
</tr>
</tbody>
</table>

* Agrotain was the urease inhibitor used for the NBPT-treated urea.

Table 3. Cumulative NH$_3$ volatilization as affected by the N fertilizer source and sampling time (Day) interaction at the Arkansas Agricultural Research and Extension Center at Fayetteville during the 2010 to 2011 growing season.

<table>
<thead>
<tr>
<th>Day</th>
<th>(NH$_4$)$_2$SO$_4$</th>
<th>NBPT-treated urea</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.082</td>
<td>0.033</td>
<td>0.815</td>
</tr>
<tr>
<td>6</td>
<td>0.118</td>
<td>0.128</td>
<td>1.736</td>
</tr>
<tr>
<td>9</td>
<td>0.148</td>
<td>0.424</td>
<td>2.325</td>
</tr>
<tr>
<td>12</td>
<td>0.154</td>
<td>0.605</td>
<td>2.507</td>
</tr>
<tr>
<td>15</td>
<td>0.157</td>
<td>0.676</td>
<td>2.584</td>
</tr>
<tr>
<td>18</td>
<td>0.159</td>
<td>0.718</td>
<td>2.619</td>
</tr>
</tbody>
</table>

P-value: <0.001

LSD(0.10) 0.271 (compare days within same N source)

LSD(0.10) 0.724 (compare two N sources)

* Agrotain was the urease inhibitor used for the NBPT-treated urea.