Effect of urease inhibitors and cationic materials on growth response and ammonia volatilization following fertilization of Kentucky bluegrass (Poa pratensis L.) with urea

Young Kyoo Joo
Iowa State University

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Effect of urease inhibitors and cationic materials on growth response and ammonia volatilization following fertilization of Kentucky bluegrass (Poa pratensis L.) with urea

Joo, Young Kyoo, Ph.D.

Iowa State University, 1987
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Effect of urease inhibitors and cationic materials on growth response and ammonia volatilization following fertilization of Kentucky bluegrass (Poa pratensis L.) with urea

by

Young Kyoo Joo

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY
Major: Horticulture

Approved: Members of the Committee

In Charge of Major Work
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Iowa State University
Ames, Iowa
1987
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GENERAL INTRODUCTION

Urea is a dominant form of nitrogen (N) fertilizer in world agriculture, and it is now a major source of N fertilizer for the turf industry because of its low cost, relatively low salt index, and its compatibility in tank-mixed solutions with many of the pesticides used on lawns. The surface application of urea, in both solid and liquid forms, involves the risk of considerable N loss to the atmosphere as gaseous ammonia (NH₃). This gaseous NH₃ released from soil and/or plant surfaces to the atmosphere is commonly called ammonia volatilization. The subject has been reviewed in depth by many researchers (Terman, 1979; Freney et al., 1983; Vlek and Craswell, 1981; Nelson, 1982). Among the factors that affect NH₃ volatilization are urease activity, soil pH, temperature, soil moisture content, soil characteristics, wind speed, and rate and method of urea application (Ernst and Massey, 1960; Gasser, 1964; Overrein and Moe, 1967; Tomlinson, 1970; Vlek and Stumpe, 1978; Hargrove and Kissel, 1979; Mulvaney and Bremner, 1981; Bouwmeester et al., 1985; O'Toole et al., 1985; Ferguson and Kissel, 1986). Torello and Wehner (1983) demonstrated that urease activity within a turf thatch layer and urease activity associated with grass tissue were 18 to 30 times higher than from the underlying soil. Their findings suggest that, when urea is applied to turf, the high urease levels in thatch could result in greater NH₃ volatilization regardless of the type of underlying soil than is normally observed in other types of soil-plant systems.

Several approaches have been taken to decrease the risk of losing N
as NH$_3$ from urea. They include: (i) coating urea to slow its rate of dissolution; (ii) using a chemical that inhibits urease activity; (iii) changing the physical and/or chemical characteristics of urea, and (iv) improving urea management techniques (Hauck, 1984). The approach of using urease inhibitors has received considerable attention during the past 15 years, and numerous compounds have been proposed or patented as soil urease inhibitors (Bremner and Douglas, 1971; Bremner and Mulvaney, 1978; Mulvaney and Bremner, 1981; Hauck, 1984; Martens and Bremner, 1984). Most of these compounds are not very effective and only phenylphosphorodiamidate (PPD) has attracted significant attention. This compound was among a group of phosphoroamides patented by Held et al. (1976) for reducing gaseous loss of urea-N as ammonia when urea fertilizer is applied to soil, and recent work (Martens and Bremner, 1984) indicated that it was more effective than compounds previously proposed for inhibition of urease activity in soil. However, subsequent work (Bremner and Chai, 1986; Chai and Bremner, 1986) showed that N-(n-butyl) thiophosphoric triamide (NBPT) is considerably more effective than PPD for retarding urea hydrolysis in soil and merits serious consideration as a fertilizer amendment for retarding hydrolysis of urea fertilizer by soil urease. Ammonium thiosulfate (ATS) also has been proposed by Goos (1985) to have some urease inhibiting characteristics in soil.

Another concept concerning the reduction of NH$_3$ loss from surface-applied urea was presented by Fenn (Fenn et al., 1981, 1982a, 1982b), who studied the use of Ca$^{++}$, NH$_4^+$, K$^+$, and Mg$^{++}$ to reduce NH$_3$ volatilization.
By their theory, the rapid conversion of urea to ammonium carbonate is responsible for the high ammonia losses. Cations in combination with urea are believed to reduce the rate at which urea decomposes. Urea in the presence of cations persist on the soil surface for some period. Rappaport and Axley (1984) also suggested the use of the cation potassium \((K^+\)) as potassium chloride \((KCl)\) to improve urea-\(N\) efficiency by reducing \(NH_3\) volatilization.

The purpose of the work reported in this dissertation was to evaluate the urease inhibitors phenylphosphorodiamidate \((PPD)\), \(\text{N-}(n\text{-butyl})\) thiophosphoric triamide \((\text{NBPT})\), and ammonium thiosulfate \((\text{ATS})\) and to evaluate the cationic materials potassium \((K^+\)) and magnesium \((Mg^{++}\)) as fertilizer amendments for increasing urea-\(N\) efficiency by measuring the effect of these compounds on growth response and \(NH_3\) volatilization following their application with urea to Kentucky bluegrass \((Poa pratensis\text{ L.})\) turf. The growth response study included a growth chamber test and a three-year field test. The \(NH_3\) volatilization study included a field measurement and a growth chamber measurement using force-draft systems.
PAPER I. THE RESPONSE OF KENTUCKY BLUEGRASS TURF TO

PHENYLPHOSPHORODIAMIDATE (PPD) AND MAGNESIUM (Mg++) APPLIED

IN COMBINATION WITH UREA
The Response of Kentucky Bluegrass Turf to Phenylphosphorodiamidate (PPD) and Magnesium (Mg\textsuperscript{2+}) Applied in Combination with Urea

Y. K. Joo and N. E. Christians

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\textsuperscript{1}Contribution from the Department of Horticulture, Iowa State University. Published as Journal Paper No. J-11998 of the Iowa Agriculture and Home Economics Experiment Station, Ames. Project 2231.

\textsuperscript{2}Graduate Research Assistant and Associate Professor, respectively. Department of Horticulture, Iowa State University. Ames, Iowa 50011.
ABSTRACT

Surface-applied urea involves the risk of considerable nitrogen (N) loss to the atmosphere as gaseous ammonia (NH$_3$). Among the methods that have been proposed to reduce this N loss are the application of urea with urease inhibitors or the combinations of urea with cationic materials. The objectives of this field test were to observe the effects of the urease inhibitor Phenylphosphorodiamidate (PPD) and the effects of magnesium chloride (MgCl$_2$) on foliar burn, turf quality, and clipping yield of Kentucky bluegrass turf treated with surface-applied urea. In the heat of July, the Mg$^{++}$ treatment resulted in significant foliar burn, but it reduced burn in the relatively cool temperatures of September. The fresh weight of clippings after treatment with 2% PPD was observed to increase 20 to 31%. This result indicates that 2% PPD can have an effect on the N-use efficiency of surface-applied urea on Kentucky bluegrass turf. Magnesium (Mg$^{++}$) produced a 13% to 25% increase of clipping yield at the rate of 1 lb N/1000 ft$^2$ in August and September, but a 20% decrease at the rate of 2 lb N/1000 ft$^2$ in August. This result indicates that the cation Mg$^{++}$ may have a positive effect on the reduction of ammonia volatilization and increase urea nitrogen efficiency with low concentration under cool-temperature conditions. However, Mg$^{++}$ may increase phytotoxicity of fertilizer solutions at high concentrations in times of environmental stress.

Additional index words: Urease inhibitors, Cationic material.
Ammonia volatilization, Phenylphosphorodiamidate, Magnesium chloride, Foliar burn, Turfgrass.
INTRODUCTION

The use of urea on turfgrass areas has increased during the past 20 years, and it is now a major source of nitrogen (N) for fertilization programs used on golf courses, home lawns, and athletic fields. Urea can be applied in dry and/or liquid forms. Because of its versatility, liquid fertilization is rapidly becoming the most popular method of applying urea to turfgrasses.

Many researchers, however, have reported that the surface application of urea involves the risk of considerable N loss to the atmosphere as gaseous ammonia (NH$_3$), and field studies have shown urea to be less efficient than other N sources when surface-applied on grass sod (Volk, 1959; Gasser, 1964; Tomlinson, 1970). Laboratory studies have been conducted to investigate NH$_3$ volatilization from urea and the factors which affect it. Among these factors are the urease activity of the soil, pH, temperature, water content, NH$_3$ sorbing capacity of the soil, and rate and method of urea application (Ernst and Massey, 1960; Gasser, 1964; Overrein and Moe, 1967; Tomlinson, 1970; Hargrove and Kissel, 1979; Mulvaney and Bremner, 1981).

In 1983, Torello and Wehner (1983) demonstrated that urease activity within a turf thatch layer and urease activity associated with turfgrass tissue were very high compared with activities in underlying soil. Their findings suggest that, when urea is applied to turf, the high urease levels in thatch could result in greater NH$_3$ volatilization than is normally observed in other types of crop production.
Various compounds capable of reducing gaseous loss of NH$_3$ by retardation of urea hydrolysis in soils have been studied, and many compounds have been patented as urease inhibitors (Bremner and Douglas, 1971b; Mulvaney and Bremner, 1981). Researchers at Iowa State University and the Tennessee Valley Authority have studied the effect of urease inhibitors on transformations of urea N in soils. They found that Phenylphosphorodiamidate (PPD) was the most effective urease inhibitor and have reported that it reduces ammonia volatilization and urea hydrolysis under various environmental conditions (Bremner and Douglas, 1971a, 1971b; Bremner and Mulvaney, 1978; Mulvaney and Bremner, 1981; Marten and Bremner, 1982; Hauck, 1983). East German researchers have demonstrated that PPD improves the urea efficiency in pot experiments with oats, ryegrass, and wheat (Heber et al., 1979; Matzel et al., 1979). In 1983, workers in the Syracuse Research Laboratory studied the role of urease inhibitors in increasing efficiency of surface-applied urea and in increasing corn yield in the field. They demonstrated the greater potential for NH$_3$ losses from reduced-tillage systems and proposed the use of urease inhibitors in keeping these losses to a minimum (Hendrickson et al., 1983; O'Connor et al., 1983; Omholt and Hendrickson, 1983).

Another concept concerning the reduction of NH$_3$ loss from surface-applied urea was presented by Fenn (Fenn et al., 1981, 1982a, 1982b). They have studied the use of Ca$^{++}$, NH$_3$, K$^+$, and Mg$^{++}$ to reduce NH$_3$ volatilization. In the absence of cations, all urea on the soil surface is reported to be converted to other forms of nitrogen in two to three
days. The extremely rapid conversion of urea to ammonium carbonate is believed to be responsible for the high ammonia losses. However, cations in combination with urea are believed to reduce the rate at which urea decomposes. Large quantities of urea in the presence of cations may persist on the soil surface for two or more weeks. The urea combined with cations on the soil surface is thought to be in equilibrium with water and will be immediately released into the soil during a rainfall or irrigation.

The objectives of this initial field test were to observe the effects of the urease inhibitor PPD and the effects of magnesium chloride on foliar burn, turf quality, and clipping yield of Kentucky bluegrass turf treated with surface-applied urea.
MATERIALS AND METHODS

This study was conducted in 1984 at the Iowa State University Turf Research Plots north of Ames, Iowa. The turf used in the study had been established in 1981 on a 'Nicollet' Aquic Hapludoll fine loamy mixed mesic soil with a pH of 7.5, 10 ppm P, 90 ppm K, and 2.3% O.M. with a blend of 25% by weight each of 'Parade', 'Adelphi', 'Glade', and 'Rugby' Kentucky bluegrass (Poa pratensis L.). The turf was watered as needed to prevent drought stress throughout the study.

The investigation was designed in a split-plot with repeated treatments and measurements on the same plot areas in four replications. The main plots included liquid urea applied at 0, 1, and 2 lb N/1000 ft². The subplots included a control, PPD at 1 and 2% of the weight of N, and Mg++, in the form of MgCl₂·6H₂O at 25% of the weight of N. The treatments were applied monthly in June through September. Each plot measured 25 ft², and each treatment was applied in the equivalent of 3 gal H₂O/1000 ft² with a CO₂ backpack sprayer operated in four different directions to assure uniform application. The degree of damage to turfgrass foliage was estimated visually three days after each application. The rating scale used ranged from 1 to 9; 9 = no visual burn, and 1 = dead turf. Data of visual quality ratings based primarily on color, uniformity, and density were collected on a weekly basis and rated on a scale of 1 – 9; 9 = best quality, 6 = acceptable, and 1 = poorest. Clipping weights were collected weekly for five weeks after each treatment at a 2-inch mowing height from two strips through the
center of the plots measuring 20 inches X 5 feet each. After data were collected, all plot areas were mowed at the 2-inch mowing height and clippings were removed.
RESULTS AND DISCUSSION

The effects of the ammonia volatilization inhibitors on fertilizer burn varied with nitrogen rate and time of application (Table 1). In the heat of July, the MgCl$_2$ treatment resulted in greater foliar burn in the plots with 2 lb N/1000 ft$^2$, but it reduced burn in the treatments with 1 and 2 lb N/1000 ft$^2$ in the relatively wet conditions and cool temperatures of September. The PPD reduced burn significantly at 1 lb N/1000 ft$^2$ in September, but those effects were not consistent across all application dates (Table 1, Figure 1).

Visual turf quality increased with increasing N rate, however, the effect varied with month of application (Table 1, Figure 2). Plots treated with PPD at 2% of the weight of N had higher quality ratings than plots receiving other inhibitor treatments (Table 1). This effect was most evident in September, although even that effect was quite small (Figure 2).

Clipping yield increased with increasing rates of N, although the response varied with month of application (Table 1, Figure 3). Where no urea was applied, there was no effect of PPD or Mg$^{++}$ on clipping yield and quality of Kentucky bluegrass (Figure 2, Figure 3). The average fresh weight of clippings over a five-week period in plots treated with 2% PPD increased 28% at 1 lb N/1000 ft$^2$ in August, 31% at 1 lb N/1000 ft$^2$ and 20% at 2 lb N/1000 ft$^2$ in September (Figure 3). This result indicates that 2% PPD can have an effect on the nitrogen efficiency of surface-applied urea on Kentucky bluegrass turf. Magnesium chloride
treatments showed a 13% to 25% increase of the fresh clipping yield at 1 lb N/1000 ft\(^2\) in August and September, but a 20% decrease at 2 lb N/1000 ft\(^2\) in August. These results indicate that the cation Mg\(^{++}\) may have a positive effect on urea nitrogen efficiency with low concentrations under cool temperature conditions. However, Mg\(^{++}\) may increase phytotoxicity of fertilizer solutions at high concentrations in times of environmental stress.
CONCLUSIONS

The results of this study do not prove that NH$_3$ volatilization was decreased by any of the inhibitor treatments; however, the positive effects of the 2% PPD and the Mg$^{++}$ treatments on the clipping yield and turf quality would indicate that, under some conditions, a reduction of N loss and an increase in N-use efficiency are possible when these materials are combined with liquid urea applications on Kentucky bluegrass turf.

More detailed studies are under way to further measure the effects of these treatments on turfgrass growth and quality and to measure the quantity of NH$_3$ volatilized from turfgrass areas treated with these materials.
LITERATURE CITED


Table 1. The analysis of variance for burn rating, turf quality, and clipping yield as affected by nitrogen levels, inhibitors (PPD, Mg$$^{++}$$) and month treated

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>Burn rating</th>
<th>Turf quality</th>
<th>Clipping yield</th>
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<tr>
<td>Nitrogen levels</td>
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<td>51.44 **</td>
<td>121.25 **</td>
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<tr>
<td>Inhibitors</td>
<td>3</td>
<td>0.23</td>
<td>0.35 *</td>
<td>2054 *</td>
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<tr>
<td>Control vs. Mg$$^{++}$$</td>
<td>(1)</td>
<td>0.02</td>
<td>0.02</td>
<td>37</td>
</tr>
<tr>
<td>Control vs. PPD 1%</td>
<td>(1)</td>
<td>0.01</td>
<td>0.01</td>
<td>455</td>
</tr>
<tr>
<td>Control vs. PPD 2%</td>
<td>(1)</td>
<td>0.13</td>
<td>0.26 **</td>
<td>552 **</td>
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<td>6</td>
<td>0.34</td>
<td>0.29</td>
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<td>Month treated</td>
<td>3</td>
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<td>4.26 **</td>
<td>81562 **</td>
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<td>2910 **</td>
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<td>9</td>
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<td>470</td>
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<td>Month X N X inhibitor</td>
<td>18</td>
<td>4.42 *</td>
<td>0.46</td>
<td>670</td>
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*, **Significant at the 0.05 and 0.01 probability levels, respectively.
Figure 1. The effects of inhibitors on foliar burn of Kentucky bluegrass turf treated with surface-applied urea.

Liquid urea was applied at 0 (NO), 1 lb N/1000 ft$^2$ (N1), and 2 lb N/1000 ft$^2$ (N2).

The rating scale used ranged from 1 to 9; 9 = no visual burn, and 1 = dead.
FOLIAR BURN 1984

INHIBITORS

CONTROL

PPD 1%

PPD 2%

MS 25%

visual rating

June July August September

N0 N1 N2 N0 N1 N2 N0 N1 N2 N0 N1 N2
Figure 2. The effects of inhibitors on turf quality of Kentucky bluegrass turf treated with surface-applied urea.

Liquid urea was applied at 0 (NO), 1 lb N/1000 ft\(^2\) (N1), and 2 lb N/1000 ft\(^2\) (N2).

The rating scale used ranged from 1 to 9; 9 = best quality, 6 = acceptable, and 1 = poorest.
TURF QUALITY 1984

INHIBITORS

CONTROL
PPD 1%
PPD 2%
Me 25%

visual rating

8.0
7.0
6.0
5.0

N0 N1 N2
June

N0 N1 N2
July

N0 N1 N2
August

N0 N1 N2
September
Figure 3. The effects of inhibitors on clipping yield of Kentucky bluegrass turf treated with surface-applied urea

Liquid urea was applied at 0 (NO), 1 lb N/1000 ft$^2$ (N1), and 2 lb N/1000 ft$^2$ (N2).

Clipping yields are based on fresh weight from the area of 16.7 ft$^2$ (1.5 m$^2$).
CLIPPING YIELD 1984

INHIBITORS

<table>
<thead>
<tr>
<th>Month</th>
<th>NO</th>
<th>N1</th>
<th>N2</th>
<th>LSD</th>
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<tr>
<td>June</td>
<td></td>
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<td>August</td>
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</tr>
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<td>September</td>
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PAPER II. THE GROWTH RESPONSE OF KENTUCKY BLUEGRASS TURF TO UREASE INHIBITORS AND CATIONIC MATERIALS APPLIED IN COMBINATION WITH UREA
The Growth Response of Kentucky Bluegrass Turf to Urease Inhibitors and Cationic Materials Applied in Combination with Urea

Y. K. Joo and N. E. Christians

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1Contribution from the Department of Horticulture, Iowa State University. Published as Journal Paper No. J- of the Iowa Agriculture and Home Economics Experiment Station, Ames. Project 2231.

2Graduate Research Assistant and Professor, respectively. Department of Horticulture, Iowa State University. Ames, Iowa 50011.
Urea is a major source of nitrogen (N) fertilizer for the turf industry. Fertilization with urea in both liquid and dry forms involves the risk of considerable N loss to the atmosphere as gaseous ammonia (NH₃). Among the methods that have been proposed to reduce this N loss are the application of urea with urease inhibitors and the combinations of urea with cationic materials. The objective of the studies reported here was to evaluate the urease inhibitors phenylphosphorodiamidate (PPD), \textit{N}-(\textit{n}-butyl) thiophosphoric triamide (NBPT), and ammonium thiosulfate (ATS) and to evaluate cationic materials potassium (K⁺) and magnesium (Mg²⁺) as fertilizer amendments for increasing urea-N efficiency by measuring the effect of these compounds on growth response following application of urea to Kentucky bluegrass \textit{(Poa pratensis L.)} turf. The first experiment conducted in growth chambers was a screening trial to evaluate PPD and MgCl₂ in combination with four rates of N (0, 49, 98, 148 kg ha⁻¹) at two temperatures (20/13, 27/18°C). The PPD was included at 1 and 2% and Mg²⁺ at 25% of the weight of N. The 25% Mg²⁺ treatment was the most effective in reducing foliar burn. This effect was more evident in the low temperature than in the high temperature treatment. The average fresh weight of clippings over a three-week period in pots treated with PPD increased at both temperature treatments.

The treatments for the two-year field test included liquid urea applied monthly in June through September in 1985 and 1986 at 49 kg N ha⁻¹ (1 lb N/1000 ft²) with the urease inhibitors PPD (1, 2, 3% of the
weight of applied N, NBPT (0.5, 1, 2%), and ATS (5, 15, 25%), and cationic materials K\(^+\) (5, 15, 25%) and Mg\(^{2+}\) (5, 15, 25%) at three rates each. The cations Mg\(^{2+}\) and K\(^+\) reduced foliar burn and increased turf quality during mid- and late summer of 1985 at the 5% rate. Clipping yield was not affected by urease inhibitors or by the cations. In 1986, under milder climatic conditions, the urease inhibitors PPD and NBPT treatments significantly increased clipping yield. The cationic materials KCl and MgCl\(_2\) reduced foliar burn and increased visual turf quality in mid-summer. Plots treated with ATS increased clipping yield at the 15% rate; however, PPD and NBPT were much more effective than the ATS treatment. Clipping yield varied with month of application, and the effect of PPD, and NBPT on percentage yield increase was greatest in heat stress periods. The fresh weight of clippings averaged over a four-week period in plots treated with 2% PPD increased 30.0% in June, 35.5% in July, 13.9% in August, and 8.3% in September as compared with the control plots. The average increase over four months was 12.0%, 21.7%, and 6.0% with the 1, 2, and 3% PPD treatments, respectively. The fresh weight of clippings averaged over a four-week period in plots treated with 2% NBPT increased 21.1% in June, 27.0% in July, 16.6% in August, and 9.9% in September over the control. The average increase over four months was 14.7%, 12.4%, and 18.4% with the 0.5, 1, and 2% NBPT treatments, respectively. Clipping yield response varied among the weeks following application. Yield increase showed a maximum in the first week at the 2% rate of PPD and decreased in weeks two through four. Yield increase reached a maximum in the second and third weeks with 0.5% treatment of
NBPT, and increased into the fourth week at the 1 and 2% rates. Responses to urea-N lasted longer at the higher levels of NBPT. The studies reported here did not measure the quantity of NH\textsubscript{3} volatilized directly; however, the positive effects of the urease inhibitors PPD and NBPT on growth response indicate that a reduction of N loss and an increase in N-use efficiency are possible when these materials are combined with liquid urea applications on Kentucky bluegrass turf. The urease inhibitors PPD and NBPT deserve further consideration as fertilizer amendments for the turfgrass industry.

Additional index words: Urease inhibitors, Phenylphosphorodiamidate, N-(n-butyl) thiophosphoric triamide, Ammonium thiosulfate, Potassium chloride, Magnesium chloride, Ammonia volatilization, Turfgrass, Fertilization.
INTRODUCTION

Urea is a major source of nitrogen (N) fertilizer for the turf industry because of its low cost, relatively low salt index, and its compatibility in tank-mixed solutions with many of the pesticides used on lawns. Because of its versatility, liquid fertilization is rapidly becoming a popular method of applying urea to turfgrasses. The disadvantages of liquid fertilization of urea include potential foliar burn and relatively short residual response (Wesely, 1983). Many researchers have reported that the surface application of urea, in both solid and liquid forms, also involves the risk of considerable N loss to the atmosphere as gaseous ammonia, and field studies have shown urea to be less efficient than other N sources when surface-applied on grass sod (Volk, 1959; Gasser, 1964; Tomlinson, 1970; Spangenberg et al., 1986).

Laboratory and greenhouse studies have been conducted to investigate NH<sub>3</sub> volatilization from urea and the factors which affect it. Among these factors are urease activity, soil pH, temperature, water content, rainfall, NH<sub>3</sub> sorbing capacity of the soil, and rate and method of urea application (Ernst and Massey, 1960; Gasser, 1964; Overrein and Moe, 1967; Tomlinson, 1970; Hargrove and Kissel, 1979; Mulvaney and Bremner, 1981; Bouwmeester et al., 1985; O'Toole et al., 1985; Ferguson and Kissel, 1986).

Torello and Wehner (1983) demonstrated that urease activity within a turf thatch layer and urease activity associated with turfgrass tissue were 18 to 30 times higher than from underlying soil. Their findings
suggest that when urea is applied to turf, the high urease levels in thatch could result in greater NH$_3$ volatilization, regardless of the soil type, than is normally observed in other types of soil-plant systems.

One approach to minimizing the problems encountered in use of urea is to find urease inhibitors that will retard urea hydrolysis when applied in combination with urea fertilizer. This approach has received considerable attention during the past 15 years, and numerous compounds have been proposed or patented as soil urease inhibitors (Bremner and Douglas, 1971; Bremner and Mulvaney, 1978; Mulvaney and Bremner, 1981; Hauck, 1984; Martens and Bremner, 1984). Most of these compounds are not very effective and only phenylphosphorodiamidate (PPD) has attracted significant attention. This compound was among a group of phosphoroamides patented by Held et al. (1976) for reducing gaseous loss of urea-N as ammonia when urea fertilizer is applied to soil, and recent work (Martens and Bremner, 1984) indicated that it was more effective than compounds previously proposed for inhibition of urease activity in soil. However, subsequent work (Bremner and Chai, 1986; Chai and Bremner, 1986) showed that N-(n-butyl) thiophosphoric triamide (NBPT) is considerably more effective than PPD for retarding urea hydrolysis in soil and merits serious consideration as a fertilizer amendment for retarding hydrolysis of urea fertilizer by soil urease. Ammonium thiosulfate (ATS) used as a N and sulfur fertilizer has also been proposed by Goos (1985) to have some urease inhibiting characteristics in soil.

Another concept concerning the reduction of NH$_3$ loss from surface-
applied urea was presented by Fenn (Fenn et al., 1981, 1982a, 1982b), who studied the use of \( \text{Ca}^{++} \), \( \text{NH}_4^+ \), \( K^+ \), and \( \text{Mg}^{++} \) to reduce \( \text{NH}_3 \) volatilization. By their theory, all urea on the soil surface is converted to other forms of N within several days of application. The extremely rapid conversion of urea to ammonium carbonate is believed to be responsible for the high ammonia losses. However, cations in combination with urea are believed to reduce the rate at which urea decomposes. Rappaport and Axley (1984) also suggested that potassium (\( K^+ \)) from potassium chloride (KCl) can potentially improve urea-N efficiency by reducing \( \text{NH}_3 \) volatilization.

In earlier field tests (1983 and 1984), the effectiveness of PPD and \( \text{MgCl}_2 \) in increasing the efficiency of surface-applied urea on turfgrass areas was evaluated. Positive results of potentially practical use on turfgrass were observed with both materials (Joo and Christians, 1984; Joo and Christians, 1986).

The objectives of the studies reported here were to evaluate the urease inhibitors phenylphosphorodiamidate (PPD), \( \text{N-}(\text{n-butyl}) \) thiophosphoric triamide (NBPT), and ammonium thiosulfate (ATS) and to evaluate the cationic materials potassium (\( K^+ \)) and magnesium (\( \text{Mg}^{++} \)) as fertilizer amendments for increasing urea-N efficiency by measuring the effect of these compounds on growth response following their application with urea to Kentucky bluegrass (\textit{Poa pratensis} L.) turf.
MATERIALS AND METHODS

A growth chamber test was conducted in 1984 and field tests were conducted in 1985 and 1986 at the Iowa State University Turfgrass Research area north of Ames, IA. The turf used in the experiments had been established in 1981 on a 'Nicollet' Aquic Hapludoll fine loamy mixed mesic soil (pH 7.5, 2.3% organic matter) with a blend of 25% by weight each of 'Parade', 'Adelphi', 'Glade', and 'Rugby' Kentucky bluegrass (*Poa pratensis* L.). The turf was irrigated as needed to prevent drought stress throughout the study.

Pot Test in Growth Chambers

The pot test was conducted as a screening trial to evaluate the effect of PPD and magnesium chloride (MgCl₂) on foliar burn and clipping yield of Kentucky bluegrass at four N rates in both high and low temperatures (Table 1).

The sod used in this test was obtained from the turf previously mentioned. Grass was transplanted in 20 cm (8 inch) diameter plastic pots in October, 1983 and allowed to grow for at least three months in the greenhouse before use. The soil used was prepared by mixing of equal volume of top soil, peat, and perlite (pH 7.3). The grasses were maintained in the greenhouse with a temperature regimes of 14 to 16°C (night)/ 20 to 22°C (day). Radiation levels were maintained during the day by sunlight and combination of metal halide and high-pressure sodium lamps. The pots were mowed weekly at a 5 cm (2 inch) height and
irrigated as needed. No additional N was supplied during growth in the greenhouse. The pots selected for each replication were aclimated in the growth chambers for one week before treatment. One growth chamber was set at a high temperature of 27/18°C (80/65°F) and the other at a low temperature of 20/13°C (68/55°F). Illumination of growth chambers were approx. 250 microeinsteins m⁻² sec⁻¹ with white fluorescent and tungsten lamps (General Electric, Inc.) with 12 hours photoperiod. All chemical treatments were applied with a spray-mist atomizer attached to an air pressure pump.

The experimental design was a split-split plot with two temperature as main plots, four levels of N as subplots, and the two PPD and one Mg⁺⁺ rates as sub-sub plots (Table 1). The study was replicated five times over a 15 week period. Temperature treatments were randomly assigned to the growth chambers for each replication.

The degree of damage to turfgrass foliage was estimated visually three days after each application. The rating scale used ranged from 1 to 9; 9 = no visual burn, and 1 = dead. Fresh clipping weights were collected weekly for three weeks after each treatment at a 5 cm (2 inch) mowing height.

Field Test in 1985 and 1986

The 1985 field test was designed in a randomized complete-block arrangement with repeated treatments and measurements on the same plot areas in four replications. The treatments included liquid urea applied at 49 kg N ha⁻¹ (1 lb N/1000 ft²) with PPD, ATS, Mg⁺⁺, and K⁺ at three...
rates each (Table 1). The 1986 field test was designed the same as the 1985 test except for the addition of NBPT (Table 1). The 1986 test was conducted on an adjacent area to the 1985 study. The treatments were applied monthly in June through September in both years. Each plot measured $2.32 \text{ m}^2$ (25 ft$^2$), and each treatment was applied in the equivalent of 500 liters H$_2$O ha$^{-1}$ (3 gallons H$_2$O/1000 ft$^2$) with a CO$_2$ backpack sprayer operated in four different directions to obtain uniform application.

The degree of damage to turfgrass foliage was estimated visually three days after each application. The rating scale used ranged from 1 to 9; 9 = no visual burn, and 1 = dead turf. Data on visual quality ratings based primarily on color, uniformity, and density were collected on a weekly basis and rated on a scale of 1 to 9; 9 = best quality, 6 = acceptable and 1 = poorest. Fresh weight of clippings were collected weekly for five weeks after each treatment at a 5 cm mowing height from two strips through the center of the plots measuring 50 cm X 1.5 m (20 inch X 5 ft) each. After data were collected, all plot areas were mowed uniformly at the 5 cm mowing height, and clippings were removed.
RESULTS AND DISCUSSION

The analysis of variance from the growth chamber test showed that foliar burn was affected by N levels and chemical treatments of PPD and MgCl₂ (Table 2). Clipping yield was significantly affected by temperature, N levels, and chemical treatments. The Mg⁺⁺ at 25% of the weight of N was the most effective treatment at reducing foliar burn. This effect was more evident in the low temperature than the high temperature treatment (Figure 1). The average fresh weight of clippings over a three-week period in pots treated with PPD increased at both temperature treatments (Figure 1). The results indicate that the PPD and the Mg⁺⁺ could have an effect on the N use efficiency of urea surface-applied to Kentucky bluegrass turf.

In 1985, the environmental conditions recorded during the growing season were not typical. The summer began with a very dry period which retarded growth of Kentucky bluegrass. The effects of the treatments on foliar burn and turf quality varied with chemical rates and time of application (Table 3, Figure 2, Figure 3). The K⁺ and Mg⁺⁺ at the 5% rate reduced foliar burn and increased turf quality during mid- and late summer, although those effects were small. Clipping yield over a four-month period varied with time of application, however, the treatment effects were not significant (Table 3, Table 4). Those results are likely due to the extended dry period in the summer of 1985 that began in late May and extended through early August.

There was less stress on the grass in the 1986 study. The cation
treatments reduced burn and increased visual turf quality in July and August (Table 3, Figure 2, Figure 3). Clipping yield increased on plots treated with PPD and NBPT as compared with the control (N alone), but there were no significant differences among the rates of PPD and NBPT. Plots treated with the 15% rate of ATS had a clipping yield increase of 15.1%; however, ATS was much less effective than PPD and NBPT (Table 4).

The effects of PPD and NBPT on the percentage yield increase as compared with the control were greatest in the heat stress period of July (Table 4, Figure 4). This was likely due to increase NH₃ volatilization and decreased N efficiency during this high temperature period. The fresh weight of clippings over a four-week period in plots treated with 2% PPD increased 30.0% in June, 35.5% in July, 13.9% in August, and 8.3% in September as compared with the control plots. The average increase over four months was 12.0% with the 1% PPD treatment, 21.7% with the 2% PPD and 6.0% with the 3% PPD treatment (Figure 4). The 2% PPD rate was the most effective on the N use efficiency of surface-applied urea, but 3% PPD may not be practical as a fertilizer amendment for Kentucky bluegrass turf.

The fresh weight of clipping yield over a four-week period in plots treated with 2% NBPT increased 21.1% in June, 27.0% in July, 16.6% in August, and 9.9% in September as compared with the control. The average increase over four months was 14.7% with the 0.5% NBPT treatment, 12.4% with the 1% NBPT and 18.4% with the 2% NBPT treatment (Figure 4). The NBPT has a potential value for increasing N use efficiency of urea-N applied as a liquid fertilizer. This effect may be possible at even
Clipping yield response varied among the weeks following application. Clipping yield increase (%) showed maximum in the first week at the 2% rate of PPD and decreased in weeks 2 through 4. Yield increase reached maximum in the second and third week with the 0.5% treatment of NBPT and increased into the fourth week at the 1 and 2% rates. Responses to urea-N lasted longer at the higher levels of NBPT (Figure 5).
CONCLUSIONS

The studies reported here did not measure the quantity of NH$_3$ volatilized directly; however, the positive effects of the urease inhibitors PPD and NBPT on growth response indicate a reduction of N loss and an increase in N use efficiency are possible when these materials are combined with liquid urea applications on Kentucky bluegrass turf. The urease inhibitors PPD and NBPT deserve further consideration as a fertilizer amendment for the turfgrass industry.
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Table 1. Experimental treatment for pot and field tests

<table>
<thead>
<tr>
<th>Experiments</th>
<th>N levels (kg ha(^{-1}))</th>
<th>Chemical rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot test in</td>
<td>0, 49, 98, 147</td>
<td>PPD 1, 2% (^a)</td>
</tr>
<tr>
<td>growth chamber</td>
<td></td>
<td>Mg(^{++}) 25%</td>
</tr>
<tr>
<td>Field test</td>
<td>49</td>
<td>PPD 1, 2, 3%</td>
</tr>
<tr>
<td>in 1985(^b)</td>
<td></td>
<td>ATS 5, 15, 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K(^+) 5, 15, 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg(^{++}) 5, 15, 25%</td>
</tr>
<tr>
<td>Field test</td>
<td>49</td>
<td>PPD 1, 2, 3%</td>
</tr>
<tr>
<td>in 1986</td>
<td></td>
<td>NBPT .5, 1, 2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ATS 5, 15, 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K(^{++}) 5, 15, 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg(^{++}) 5, 15, 25%</td>
</tr>
</tbody>
</table>

\(^a\) Base on weight of N (10% liquid urea).

\(^b\) NBPT not available in 1985.
Table 2. The analysis variance of growth chamber test for foliar burn and clipping yield as affected by temperature, N level, urease inhibitor PPD and cation material MgCl$_2$.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>Mean squares</th>
<th>Burn rating</th>
<th>Clipping yield*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1</td>
<td>3.45</td>
<td>6.44**</td>
<td></td>
</tr>
<tr>
<td>Error A</td>
<td>4</td>
<td>1.84</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>N levels</td>
<td>3</td>
<td>18.61**</td>
<td>0.82**</td>
<td></td>
</tr>
<tr>
<td>Temperature X N</td>
<td>3</td>
<td>0.44</td>
<td>0.45*</td>
<td></td>
</tr>
<tr>
<td>Error B</td>
<td>24</td>
<td>0.29</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Chemicals$^b$</td>
<td>3</td>
<td>2.29**</td>
<td>0.10*</td>
<td></td>
</tr>
<tr>
<td>Temperature X chemical</td>
<td>3</td>
<td>0.48</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>N X Chemical</td>
<td>9</td>
<td>0.88**</td>
<td>0.10*</td>
<td></td>
</tr>
<tr>
<td>Temperature X N X chemical</td>
<td>9</td>
<td>0.10</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Error C</td>
<td>96</td>
<td>0.20</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Clipping yield based on the average over three-week measurement.

$^b$Included control, PPD 1, 2%, and Mg$^{++}$ 25%.

*, **Significant at the 0.05 and 0.01 probability levels, respectively.
Table 3. The analysis of variance for foliar burn rating, turf quality and clipping yield as affected by N levels, chemical treatments, and month applied in the 1985 and 1986 field tests

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>1985 Mean squares</th>
<th></th>
<th>1986 Mean squares</th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Burn rating</td>
<td>Turf quality</td>
<td>Clipping yield</td>
<td>Burn rating</td>
</tr>
<tr>
<td>Chemicals treated</td>
<td></td>
<td>df</td>
<td></td>
<td>df</td>
<td></td>
</tr>
<tr>
<td>Control vs. PPD</td>
<td>12</td>
<td>0.61**</td>
<td>0.15**</td>
<td>267.45</td>
<td>15</td>
</tr>
<tr>
<td>Control vs. NBPT</td>
<td>(1)</td>
<td>0.81*</td>
<td>0.12*</td>
<td>117.97</td>
<td>(1)</td>
</tr>
<tr>
<td>Control vs. ATS</td>
<td>(1)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>(1)</td>
</tr>
<tr>
<td>Control vs. K+</td>
<td>(1)</td>
<td>0.22</td>
<td>0.09</td>
<td>40.75</td>
<td>(1)</td>
</tr>
<tr>
<td>Control vs. Mg**</td>
<td>(1)</td>
<td>0.26</td>
<td>0.14*</td>
<td>310.66</td>
<td>(1)</td>
</tr>
<tr>
<td>Error A</td>
<td>36</td>
<td>0.08</td>
<td>0.05</td>
<td>166.59</td>
<td>45</td>
</tr>
<tr>
<td>Month applied</td>
<td>3</td>
<td>0.35*</td>
<td>1.22**</td>
<td>34274.56**</td>
<td>3</td>
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<tr>
<td>Chemical X month</td>
<td>36</td>
<td>0.08</td>
<td>0.05*</td>
<td>39.52</td>
<td>45</td>
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<tr>
<td>Error B</td>
<td>117</td>
<td>0.13</td>
<td>0.03</td>
<td>152.88</td>
<td>144</td>
</tr>
</tbody>
</table>

^aNo data available in 1985.

*,**Significant at the 0.05 and 0.01 probability levels, respectively.
Table 4. The effect of chemical treatments on clipping yield over a four-week period following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha$^{-1}$ (1 lb N/1000 ft$^2$)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>44.0</td>
<td>93.9</td>
<td>78.9</td>
<td>47.9</td>
<td>66.2</td>
<td>84.2</td>
<td>58.9</td>
<td>62.5</td>
<td>74.4</td>
<td>70.0</td>
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<tr>
<td>PPD 1%</td>
<td>43.1</td>
<td>88.5</td>
<td>82.8</td>
<td>41.2</td>
<td>63.9</td>
<td>100.2</td>
<td>71.5</td>
<td>69.4</td>
<td>72.4</td>
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<tr>
<td>2%</td>
<td>48.7</td>
<td>94.4</td>
<td>80.0</td>
<td>42.7</td>
<td>66.4</td>
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<td>79.8</td>
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<tr>
<td>3%</td>
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<td>63.6</td>
<td>75.6</td>
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<td>NBPT .5%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>100.3</td>
<td>68.9</td>
<td>67.9</td>
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<td>80.3</td>
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<td>1%</td>
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<td>—</td>
<td>—</td>
<td>—</td>
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<td>70.4</td>
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<td>—</td>
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<td>74.8</td>
<td>72.9</td>
<td>81.8</td>
<td>82.9</td>
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<tr>
<td>ATS 5%</td>
<td>31.6</td>
<td>88.8</td>
<td>82.1</td>
<td>45.2</td>
<td>61.9</td>
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<td>69.2</td>
<td>66.5</td>
<td>74.7</td>
<td>74.5</td>
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<tr>
<td>15%</td>
<td>46.0</td>
<td>97.6</td>
<td>84.9</td>
<td>44.7</td>
<td>68.3</td>
<td>99.1</td>
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<td>69.8</td>
<td>81.2</td>
<td>80.6</td>
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<td>25%</td>
<td>47.0</td>
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<td>87.5</td>
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<td>61.3</td>
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<td>K+ 5%</td>
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<td>85.5</td>
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<td>67.4</td>
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<td>71.3</td>
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<td>25%</td>
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<td>56.9</td>
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LSD (0.05) 9.3  
LSD (0.05) 10.7

$^a$Based on fresh weight (g/1.5 m$^2$).

$^b$No data available in 1985.
Figure 1. Effect of PPD and MgCl₂ on foliar burn and clipping yield following fertilization of Kentucky bluegrass turf.

PPD and MgCl₂ were applied in combination with four rates of N at two temperatures.

Low temperature (20/13°C), high temperature (27/18°C).

Clipping yield is based on gram per pot (300 cm²).
Figure 2. The effect of KCl treatment on visual burn and turf quality over a four-week period following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha$^{-1}$ (1 lb N/1000 ft$^2$)
Figure 3. The effect of MgCl$_2$ on visual burn and turf quality over a four-week period following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha$^{-1}$ (1 lb N/1000 ft$^2$)
Figure 4. Effects of PPD and NBPT on clipping yield increase (%) over the control following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha$^{-1}$ (1 lb N/1000 ft$^2$)

The values shown are averages of weekly measurement over a four-week period in 1986.
Figure 5. Effects of PPD and NBPT on clipping yield increase (%) as compared with the control among the weeks following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha$^{-1}$ (1 lb N/1000 ft$^2$)

The values shown are averages over a four-month period in 1986.
LSD .05 = 15.0

- NBPT .5% X NBPT 1%
- NBPT 2%

LSD .05 = 12.8

- PPD 1% X PPD 2%
- PPD 3%

% YIELD INCREASE

WEEK 1  WEEK 2  WEEK 3  WEEK 4
PAPER III. EFFECT OF N-(n-BUTYL) THIOPHOSCHORIC TRIAMIDE (NBPT) ON GROWTH RESPONSE AND AMMONIA VOLATILIZATION FOLLOWING FERTILIZATION OF KENTUCKY BLUEGRASS (Poa pratensis L.) WITH UREA.
Effect of N-(n-Butyl) Thiophosphoric Triamide (NBPT) on Growth Response and Ammonia Volatilization Following Fertilization of Kentucky Bluegrass (Poa pratensis L.) with Urea

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1Contribution from the Department of Horticulture, Iowa State University. Published as Journal Paper No. J-12608 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Project 2231.

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ABSTRACT

The surface application of urea fertilizers to grass sod involves the risk of nitrogen (N) loss to the atmosphere as gaseous ammonia (NH₃). Amendment of urea fertilizers with urease inhibitors has been proposed as a method to reduce this N loss. The objectives of these studies were to evaluate the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) as a fertilizer amendment for increasing urea-N efficiency by measuring the effect of this compound on growth response and NH₃ volatilization following application of urea to Kentucky bluegrass. The treatments for the growth response study included liquid urea applied monthly in June through September in 1986 at 1 lb N/1000 ft² (49 kg N ha⁻¹) with NBPT at 0, 0.5, 1.0, and 2.0% of the weight of N. The effect of NBPT on turf quality varied with NBPT levels and time of application. Application of NBPT increased clipping yield significantly, but the effect varied with the month of application. The clipping yield response lasted longer at the higher rates of NBPT. The effect of NBPT on NH₃ volatilization was measured on Kentucky bluegrass turf under field conditions. The urea treatments and the NBPT rates for the second study were the same as in the growth response study. Total N loss through NH₃ volatilization in the 4 days following treatment with urea was 18.5% of the applied N (1 lb N/1000 ft²) in the absence of NBPT, 6.9% with both 0.5 and 1.0% NBPT, and 5.6% with 2.0% NBPT. Percentage reduction of urea-N loss through NH₃ volatilization in 4 days was 62.2% with 0.5% NBPT, 62.9% with 1.0% NBPT, and 69.9% with 2.0% NBPT. These results indicate that NBPT has potential
value for increasing N use efficiency of urea-N applied as a liquid fertilizer to Kentucky bluegrass by reducing NH$_3$ volatilization.

Additional index words: Urease inhibitor, Ammonia volatilization, N-(n-Butyl) thiophosphoric triamide, Turfgrass, Lawn, Fertilization.
INTRODUCTION

The use of urea as a nitrogen (N) fertilizer has increased dramatically during the past 20 years. Solid urea makes up more than 60% of the total dry N fertilizer marketed, and the use of liquid N solutions containing urea continues to increase (Russel, 1984). Urea use on turfgrass areas has increased rapidly, and urea is now a major source of N for fertilization of golf courses, home lawns, and athletic fields. Urea may be applied in both dry and liquid forms. Because of its versatility, the liquid form is rapidly becoming the most popular method of applying urea to turfgrass areas.

Many researchers have reported that surface application of urea involves the risk of considerable N loss to the atmosphere as gaseous ammonia (NH$_3$), and field studies have shown urea to be less efficient than other N sources when surface-applied on grass sod (Volk, 1959; Gasser, 1964; Tomlinson, 1970). Problems with urea also include damage to germinating seeds and seedling plants, and nitrite and/or ammonia toxicity (Gasser, 1964; Tomlinson, 1970). Torello and Wehner (1983) demonstrated that urease activity within a turf thatch layer and urease activity associated with turfgrass tissue were very high compared with activities in underlying soil. Their findings suggested that, when urea is applied to turf, the high urease levels in thatch could result in greater NH$_3$ volatilization than is normally observed in other types of soil-plant systems.

One approach to minimizing the problems encountered in use of urea
is to find urease inhibitors that will retard urea hydrolysis when applied in combination with urea fertilizer. This approach has received considerable attention during the past 15 years, and numerous compounds have been proposed or patented as soil urease inhibitors (Bremner and Douglas, 1971; Bremner and Mulvaney, 1978; Mulvaney and Bremner, 1981; Hauck, 1984; Martens and Bremner, 1984). Most of these compounds are not very effective and only phenylphosphorodiamidate (PPD) has attracted significant attention. This compound was among a group of phosphoroamides patented by Held et al. (1976) for reducing gaseous loss of urea-N as ammonia when urea fertilizer is applied to soil, and recent work (Martens and Bremner, 1984) indicated that it was more effective than compounds previously proposed for inhibition of urease activity in soil. However, subsequent work (Bremner and Chai, 1986; Chai and Bremner, 1986) showed that N-butyl phosphorothioc triamide (NBPT) [now usually referred to as N-(n-butyl) thiophosphoric triamide] is considerably more effective than PPD for retarding urea hydrolysis in soil and merits serious consideration as a fertilizer amendment for retarding hydrolysis of urea fertilizer by soil urease.

The objective of the field studies reported here was to evaluate the urease inhibitor NBPT as a fertilizer amendment for increasing urea-N efficiency by measuring the effect of this compound on growth response and ammonia volatilization following application of urea to Kentucky bluegrass.
MATERIALS AND METHODS

The experiments reported here were conducted in 1986 at the Iowa State University Turfgrass Research Plots north of Ames, IA. The turf used in the study had been established in 1981 on a 'Nicollet' Aquic Hapludoll fine loamy mixed mesic soil (pH 7.5, 2.3% organic matter) with a blend of 25% by weight each of 'Parade', 'Adelphi', 'Glade', and 'Rugby' Kentucky bluegrass (*Poa pratensis* L.). The turf was irrigated as needed to prevent drought stress throughout the study.

Growth Response Study

A field study was designed in a randomized complete-block arrangement with repeated treatments and measurements on the same plot areas in four replications. The treatments included liquid urea applied at 1 lb N/1000 ft^2^ (49 kg N ha⁻¹) with NBPT at 0 (control), 0.5, 1.0, and 2.0% of the weight of N. The treatments were applied monthly in June through September in 1986. Each plot measured 25 ft^2^ (2.32 m^2^), and each treatment was applied in the equivalent of 3 gallons H₂O/1000 ft^2^ (495 liters ha⁻¹) with a CO₂ backpack sprayer operated in four different directions to obtain uniform application. Data on visual quality ratings based primarily on color, uniformity, and density were collected on a weekly basis. Clipping weights were collected weekly for four weeks after each treatment at a 2-inch (5 cm) mowing height from two strips through the center of the plots measuring 20 inches × 5 feet each (area 1.5 m^2^). After data were collected, all plot areas were mowed uniformly
at the 2-inch (5 cm) mowing height, and clippings were removed.

Measurement of Ammonia Volatilization

Four plexiglass chambers were constructed for field measurement of ammonia volatilization from turf fertilized with liquid urea. Each chamber was 7 inches long, 10 inches wide, and 7 inches high [volume approx. 2 gallons (8 liters)] and was attached to a steel base that had been driven 6 inches into the soil (Figure 1). Approximately 1 gallons of air per minute were passed over the sampling area (7" X 10") of each chamber and into a trap containing 5 fluid ounces (150 ml) of 0.25 N sulfuric acid. An air compressor fitted with a regulator and a reserve tank was used as the air source. The air from the compressor was passed through Drierite® (anhydrous CaSO₄) and then distributed to the four volatilization chambers via a manifold. The urea and NBPT treatments were the same as in the growth response test. All treatments were applied with a spray-mist atomizer attached to an air pressure pump. Turf areas were mowed at 2-inch height and irrigated with 1 inch of water 3 hours before treatments. Ammonia trapping samples were collected at 0.25, 1, 2, 3, and 4 days after each treatment and analyzed for total N by a semimicro-Kjeldahl procedure (Bremner and Breitenbeck, 1983).
RESULTS AND DISCUSSION

Growth Response Study

The effect of NBPT on turf quality varied with NBPT rate and month of application. There were also differing effects of NBPT among the weeks following treatment (Table 1).

Clipping yield increased on plots treated with NBPT as compared with the control (N alone), but there were no significant differences among the three rates of NBPT (Table 1). Clipping yield varied with month of application, and the effect of NBPT on percentage yield increase was greatest in the stress period of July (Table 1, Figure 2). This was likely due to increased volatilization during this high temperature period. The fresh weight of clipping yield over a four-week period in plots treated with 2% NBPT increased 21.1% in June, 27.0% in July, 16.6% in August, and 9.9% in September as compared with the control. The average increase over four months was 14.7% with the 0.5% NBPT treatment, 12.4% with the 1.0% NBPT treatment, and 18.4% with the 2.0% NBPT treatment (Figure 2). The clipping yield response varied among the weeks measured. The greatest response was observed in the second week after treatment (Table 1, Figure 3). Percentage yield increases reached a maximum in the second and third week at the 0.5% rate of NBPT. However, increases into the fourth week were shown at the higher rates of 1.0 and 2.0% treatment, and responses to urea-N lasted longer at the higher levels of NBPT (Figure 3).
Measurement of Ammonia Volatilization

Accumulative N loss from the control (N alone) in the form of ammonia was 2.9% of applied urea-N in 6 hours, 7.0% at one day, and 18.5% at the end of the fourth day. When NBPT was combined with liquid urea, the total loss of urea-N as ammonia in four days was 6.9% at both 0.5% and 1.0% NBPT, and 5.6% at 2.0% NBPT. Percentage inhibition by NBPT of volatilization of urea-N as ammonia was calculated from \((C-T) / C \times 100\), where \(C\) = amount of urea-N volatilized from the control area and \(T\) = amount of urea-N volatilized from the area treated with NBPT. Percentage inhibition of ammonia volatilization in four days was 62.6% with 0.5% NBPT, 62.9% with 1.0% NBPT, and 69.6% with 2.0% NBPT (Figure 4).
CONCLUSION

The studies reported indicate that NBPT has potential for increasing N use efficiency of urea-N applied as a liquid fertilizer to Kentucky bluegrass by reducing ammonia volatilization and that it deserves further evaluation as a fertilizer amendment for reduction of ammonia volatilization and other problems encountered in the use of urea fertilizers.


Soc. 113:1-76.


Table 1. The analysis of variance for turf quality and clipping yield as affected by urease inhibitor NBPT, month treated, and week measured

<table>
<thead>
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<th>Source of variance</th>
<th>df</th>
<th>Mean squares</th>
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<td></td>
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<td>Turf quality</td>
<td>Clipping yield</td>
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<td>NBPT rates</td>
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<td>Control vs. NBPT</td>
<td>(1)</td>
<td>0.13 *</td>
<td>5422 **</td>
<td></td>
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<tr>
<td>Among rates</td>
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<td></td>
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<tr>
<td>Month treated</td>
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*,**Significant at the 0.05 and 0.01 probability levels, respectively.
Figure 1. Plexiglass chamber and steel base used for field measurement of ammonia volatilization
PLEXIGLASS CHAMBER

TO AMMONIA TRAP

10"

7"

7"

12.5"

9.5"

STEEL BASE

6"

10"
Figure 2. Effect of NBPT on clipping yield of Kentucky bluegrass treated with surface-applied urea

Liquid urea was applied at the rate of 1 lb N/1000 ft$^2$ (49 kg N ha$^{-1}$).
Figure 3. Effect of NBPT on clipping yield among the weeks after treatment. The values shown are averages over a four-month period in 1986.

Liquid urea was applied at the rate of 1 lb N/1000 ft² (49 kg N ha⁻¹).
RESULTS

**WEEK 2**
- **CONTROL**
- **NBPT 0.5%**
- **NBPT 1.0%**
- **NBPT 2.0%**

**WEEK 3**
- **CONTROL**
- **NBPT 0.5%**
- **NBPT 1.0%**
- **NBPT 2.0%**

**WEEK 4**
- **CONTROL**
- **NBPT 0.5%**
- **NBPT 1.0%**
- **NBPT 2.0%**
Figure 4. Effect of NBPT on N loss through ammonia volatilization from Kentucky bluegrass turf treated with surface-applied urea

Liquid urea was applied at the rate of 1 lb N/1000 ft² (49 kg N ha⁻¹).
CONTROL X NBPT 0.5%
• NBPT 1.0%  O NBPT 2.0%

DAYS AFTER TREATMENT

ACUMULATIVE % IN LOSS

DAYS AFTER TREATMENT

% INHIBITION OF NBPT LOSS

NBPT 0.5%  NBPT 1.0%  NBPT 2.0%
PAPER IV. EFFECT OF UREASE INHIBITORS AND CATIONIC MATERIALS ON AMMONIA VOLATILIZATION FOLLOWING FERTILIZATION OF KENTUCKY BLUEGRASS (Poa pratensis L.) WITH UREA
Effect of Urease Inhibitors and Cationic Materials on Ammonia Volatilization Following Fertilization of Kentucky Bluegrass (Poa pratensis L.) with Urea

Y. K. Joo, N. E. Christians, and J. M. Bremner

1Contribution from the Department of Horticulture, Iowa State University. Published as Journal Paper No. J- of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Project 2231.

2Graduate Research Assistant, Professor, Department of Horticulture, and Distinguished Professor, Department of Agronomy, Iowa State University. Ames, IA 50011.
ABSTRACT

Surface-applied urea fertilizer involves the risk of considerable nitrogen (N) loss to the atmosphere as gaseous ammonia (NH₃). Among the methods that have been proposed to reduce this N loss are the amendment of urea with urease inhibitors or cationic materials. The objectives of these field and growth chamber studies were to evaluate the urease inhibitors phenylphosphorodiamidate (PPD), N-(n-butyl) thiophosphoric triamide (NBPT), and ammonium thiosulfate (ATS), and the cations potassium (K⁺) and magnesium (Mg⁺⁺) as a fertilizer amendments for increasing urea-N efficiency by measuring the effect of these compounds on NH₃ volatilization following application of urea to Kentucky bluegrass (Poa Pratensis L.). The treatments for both field and growth chamber studies included 10% liquid urea at 49 kg N ha⁻¹ (1 lb N/1000 ft²). The chemical compounds used in the field measurement of NH₃ volatilization included NBPT at 0.5, 1, and 2%, PPD 1, 2, and 3%, ATS 5, 15, and 25%, K⁺ 5, 15, and 25%, and Mg⁺⁺ 5, 15, and 25% of the weight of applied N. Total N loss through NH₃ volatilization from field measurement in the 4 days following treatment was 18.5% of the applied N in the control (N alone). When NBPT was combined with liquid urea, the total loss of urea-N as NH₃ in four days was 7.0%, 6.9%, and 5.6% at the 0.5, 1 and 2% NBPT treatments, respectively. The total loss of N in four days from PPD treated plots was 10.4%, 7.9%, and 7.2% loss at 1, 2, and 3% PPD rates, respectively. These figures represent a percentage inhibitions of NH₃ volatilization in four days of 62.6%, 62.9%, and 69.6% with the three
rates of NBPT, and 43.8%, 57.3%, and 61.1% with the three rates of PPD. Application of ATS and cationic materials K$^+$ and Mg$^{++}$ resulted in similar trends of volatilization to those of the control. The effectiveness of the materials on the reduction of NH$_3$ volatilization following fertilization with urea decreased in the order NBPT $>$ PPD $>$ ATS $>$ K$^+$ $>$ Mg$^{++}$.

The treatments used in the growth chamber measurements included NBPT at 0.125, 0.25, 0.5, and 1%, and PPD at 0.5, 1, and 2% of the weight of N. Accumulative N loss through NH$_3$ volatilization from the control (N alone) was 15.5% of applied urea-N in one day, and 24.1% in the second day, and 49.9% at the end of the seventh day. Peak NH$_3$ loss occurred the first day after applications without combination of urease inhibitors, however, the peak occurred in the second day when the urea was combined with urease inhibitors. When NBPT was combined with liquid urea, the total loss of urea-N as NH$_3$ in seven days was 29.0%, 24.6%, 22.8%, and 20.4% at the 0.125, 0.25, 0.5 and 1% NBPT rates, respectively. Total loss of N in seven days from PPD treatments was 32.8%, 26.7%, and 24.2% at the 0.5, 1, and 2% rates, respectively. Percentage inhibition of NH$_3$ volatilization as compared with the control was 41.8%, 50.7%, 54.2%, and 59.2% with 0.125, 0.25, 0.5, and 1% NBPT, respectively. The PPD treatments reduced NH$_3$ volatilization 34.3, 46.5, and 50.1% at the 0.5, 1, and 2% PPD treatments, respectively. The results indicate that NBPT and PPD have potential for increasing N use efficiency of urea-N applied as a liquid fertilizer to Kentucky bluegrass by reducing ammonia volatilization. NBPT was the most effective of the two materials in
these studies, but both should be further evaluated in field and laboratory conditions.

Additional index words: Urease inhibitors, Phenylphosphorodiamidate, $\text{N}-(\text{n-butyl})$ thiophosphoric triamide, Ammonium thiosulfate, Potassium chloride, Magnesium chloride, Ammonia volatilization, Turfgrass, Fertilization.
INTRODUCTION

Urea is the dominant form of nitrogen (N) fertilizer in world agriculture. Solid urea and N solutions that contain urea account for about 25% of the N used of U.S., and 80% of Asian consumption (Hauck, 1984). Urea is also a major source of N fertilizer for the turf industry because of its low cost, relatively low salt index, and its compatibility in tank-mixed solutions with many of the pesticides used on lawns. The surface application of urea, in both solid and liquid forms, involves the risk of considerable N loss to the atmosphere as gaseous ammonia (\(\text{NH}_3\)) by volatilization (Terman, 1979; Freney et al., 1983; Vlek and Craswell, 1981; Nelson, 1982).

Among the factors that affect \(\text{NH}_3\) volatilization are urease activity, soil pH, temperature, soil moisture content, soil characteristics, wind speed, and rate and method of urea application (Ernst and Massey, 1960; Gasser, 1964; Overrein and Moe, 1967; Tomlinson, 1970; Vlek and Stumpe, 1978; Hargrove and Kissel, 1979; Mulvaney and Bremner, 1981; Bouwmeester et al., 1985; O'Toole et al., 1985; Ferguson and Kissel, 1986). Torello and Wehner (1983) demonstrated that urease activity within a turf thatch layer and urease activity associated with grass tissue were 18 to 30 times higher than from underlying soil. Their findings suggest that, when urea is applied to turf, the high urease levels in thatch could result in greater \(\text{NH}_3\) volatilization regardless of the type of underlying soil than is normally observed in other types of soil-plant systems.
Several approaches have been taken to decrease the risk of losing N as NH₃ from urea. They include: (i) coating urea to slow its rate of dissolution; (ii) using a chemical that inhibits urease activity; (iii) changing the physical and/or chemical characteristics of urea, and (iv) improving urea management techniques (Hauck, 1984). The approach to find urease inhibitors has received considerable attention during the past 15 years, and numerous compounds have been proposed or patented as soil urease inhibitors (Bremner and Douglas, 1971; Bremner and Mulvaney, 1978; Mulvaney and Bremner, 1981; Hauck, 1984; Martens and Bremner, 1984). Most of these compounds are not very effective and only phenylphosphorodiamidate (PPD) has attracted significant attention. This compound was among a group of phosphoroamides patented by Held et al. (1976) for reducing gaseous loss of urea-N as ammonia when urea fertilizer is applied to soil, and recent work (Martens and Bremner, 1984) indicated that it was more effective than compounds previously proposed for inhibition of urease activity in soil. However, subsequent work (Bremner and Chai, 1986; Chai and Bremner, 1986) showed that N-(n-butyl) thiophosphoric triamide is considerably more effective than PPD for retarding urea hydrolysis in soil and merits serious consideration as a fertilizer amendment for retarding hydrolysis of urea fertilizer by soil urease. Ammonium thiosulfate (ATS) also has been proposed by Goos (1985) to have some urease inhibiting characteristics in soil.

Another concept concerning the reduction of NH₃ loss from surface-applied urea was presented by Fenn (Fenn et al., 1981, 1982a, 1982b), who studied the use of Ca⁺⁺, NH₄⁺, K⁺, and Mg⁺⁺ to reduce NH₃ volatilization.
By their theory, the rapid conversion of urea to ammonium carbonate is responsible for the high ammonia losses. Cations in combination with urea are believed to reduce the rate at which urea decomposes. Urea in the presence of cations persist on the soil surface for some period. Rappaport and Axley (1984) also suggested the use of the cation potassium (K⁺) as potassium chloride (KCl) to improve urea-N efficiency by reducing NH₃ volatilization.

Several methods of measuring NH₃ volatilization have been developed for evaluating NH₃ losses on turfgrass sod. They include early attempts at direct field measurement (Volk, 1959) and, later, force-draft systems (Simpson and Melsted, 1962; Hargrove and Kissel, 1979; Nelson, 1982; Torello et al., 1983; Wesely, 1983; Sheard and Beauchamp, 1985).

The objective of the studies was to evaluate the urease inhibitors phenylphosphorodiamidate (PPD), N-(n-butyl) thiophosphoric triamide (NBPT), and ammonium thiosulfate (ATS) and to evaluate cation potassium (K⁺) and magnesium (Mg++) as fertilizer amendments for increasing urea-N efficiency by measuring the effect of these compounds on NH₃ volatilization following application of urea to Kentucky bluegrass (Poa pratensis L.) turf.
MATERIALS AND METHODS

The measurements of NH$_3$ volatilization in the field were conducted in 1986 and the growth chamber tests in 1987. The field experiment was conducted at the Iowa State University Turfgrass Research Plots north of Ames, IA. The turf used in the study had been established in 1981 on a 'Nicollet' Aquic Hapludoll fine loamy mixed mesic soil (pH 7.5, 2.3% organic matter) with a blend of 25% by weight each of 'Parade', 'Adelphi', 'Glade', and 'Rugby' Kentucky bluegrass (Poa pratensis L.). The sod used for growth chamber test was obtained from the same area.

Field Measurements

Four plexiglass chambers were constructed for field measurement of ammonia volatilization from turf fertilized with liquid urea. Each chamber was 17.8 cm (7 inches) long, 25.4 cm (10 inches) wide, and 17.8 cm high [volume approx. 8 liter (2 gallons)] and was attached to a steel base that had been driven 15.2 cm (6 inches) into the soil (Figure 1). Approximately 4 liter (1 gallon) of air per minute were passed over the sampling area (450 cm$^2$) of each chamber and into a trap containing 150 ml (5 fluid ounces) of 0.25 N sulfuric acid. An air compressor fitted with a regulator and a reserve tank was used as the air source. The air from the compressor was passed through Drierite® (anhydrous CaSO$_4$) and then distributed to the four volatilization chambers via a manifold. The treatments included urea applied at 49 kg N ha$^{-1}$ alone and in combination with the urease inhibitors PPD (1, 2, and 3 % of the weight of N), NBPT
(0.5, 1, 2%), and ATS (5, 15, 25%), and with cation K\(^+\) (5, 15, 25%) and Mg\(^{++}\) (5, 15, 25%). Each treatment was applied in the equivalent of 500 liters ha\(^{-1}\) (3 gallons H\(_2\)O/1000 ft\(^2\)) with a spray-mist atomizer attached to an air pressure pump. Turf areas were mowed at a 5 cm (2 inch) height and irrigated with 2.5 cm of water 3 hours before treatment. Ammonia trapping samples were changed at 0.25, 1, 2, 3, and 4 days after treatment and analyzed for total N by a semimicro-Kjeldahl procedure (Bremner and Breitenbeck, 1983).

**Growth Chamber Measurement**

Kentucky bluegrass from the field areas was transplanted in 21 cm (8 1/4 inch) diameter, 16 cm (6 1/4 inch) high plastic pots (volume approx. 4 liters) in November, 1985 and allowed to grow for three months in the greenhouse before use. The soil (pH 7.3) in the pots was prepared by mixing of an equal volume of top soil, peat, and perlite. Greenhouse temperature regimes were maintained at 14 to 16\(^\circ\)C (night)/ 20 to 22\(^\circ\)C (day). The pots were regularly irrigated and mowed weekly at a 5 cm (2 inch) height. The sod received an additional 49 kg N ha\(^{-1}\) during early growth period in greenhouse.

A forced-draft system with an air flow rate of approximately 1 liter (1/4 gallon) of air per minute passing over the 450 cm\(^2\) sampling area of the grass pot was developed for measuring NH\(_3\) volatilization in a growth chamber (Figure 2). Compressed air was passed through a coalescing filter (Balston BX\(^\circ\)) to remove oil and dust, washed, humidified, and then distributed to the nine volatilization desiccators via a manifold. The
air passed through a trap containing 100 ml of 0.25 N sulfuric acid. The
growth chamber was set at the temperature of 27/18°C (80/65°F).
Illumination of growth chamber was approximately 300 microeinsteins
m⁻²sec⁻¹ with white fluorescent and tungsten lamps (General Electric,
Inc.) with a 12 hours photoperiod. The treatments included PPD (0.5, 1,
2% of N) and NBPT (0.125, 0.25, 0.5, 1%) combined with 10% urea solution
at a rate of 49 kg N ha⁻¹ applied with a spray-mist atomizer attached to
an air pressure pump.

The experimental design was a randomized complete block arrangement
with four replications repeated in time. Turf areas were mowed at a 5 cm
height and irrigated with 2.5 g/cm² of water one day before treatment.
Ammonia trapping samples were changed every day and analyzed for total N
by a semimicro-Kjeldahl procedure (Bremner and Breitenbeck, 1983).
RESULTS AND DISCUSSION

Field Measurement

Accumulative N loss from the control (N alone) in the form of NH$_3$ was 2.9% of applied urea-N in six hours, 7.0% at one day, and 18.5% at the end of the fourth day. Peak NH$_3$ loss occurred the second day after applications. When NBPT was combined with liquid urea, the total loss of urea-N as NH$_3$ in four days was 7.0%, 6.9%, and 5.6% at the 0.5, 1, and 2% NBPT rates, respectively (Table 1). The total loss of N in four days from PPD treated pots was 10.4%, 7.9%, and 7.2% loss at 1, 2, and 3% rates, respectively. Application of ATS, KCl, and MgCl$_2$ resulted in similar volatilization to that of the control (Table 1).

Percentage inhibition of urea-N loss as NH$_3$ was calculated from \( \frac{(C-T)}{C} \times 100 \), where C = amount of urea-N volatilized from the control area and T = amount of urea-N volatilized from the area treated with urea and chemicals. Percentage inhibition of NH$_3$ volatilization in four days was 62.6%, 62.9%, and 69.6% with the 0.5, 1, and 2% NBPT treatments, respectively (Figure 3). The PPD treatment reduced NH$_3$ volatilization 43.8, 57.3, and 61.1% at 1, 2, 3% rates, respectively. The ATS treatments reduced N loss through NH$_3$ volatilization from 21.6 to 24.3%, KCl reduced it approximately 17%, and MgCl$_2$ reduced it approximately 15% over the four day period (Figure 3). The effectiveness of the treatments on the reduction of NH$_3$ volatilization following fertilization with urea decreased in the order NBPT > PPD >> ATS > K$^+$ > Mg$^{++}$ with ATS, KCl, and MgCl$_2$ showing little practical value.
Growth Chamber Measurements

The analysis of variance from the growth chamber test showed that NH$_3$ volatilization was affected by urease inhibitor treatments (three rates of PPD and four rates of NBPT). The quantity of NH$_3$ volatilized varied by time measured (Table 2). The results from the ANOVA indicate that PPD and NBPT may have an effect on the N use efficiency of urea surface-applied to Kentucky bluegrass turf and that their activities vary through the days after treatment.

Accumulative N loss through NH$_3$ volatilization from the control (N alone) was 15.5% in one day, 24.1% by the second day, and 49.9% at the end of the seventh day. Total N loss in a week calculated by subtracting background NH$_3$-N from the blank (no treatment) was 43.0% of N applied. Peak NH$_3$ loss occurred the first day after application from the control; however, the peak occurred at the second day from the urease inhibitor treatments (Figure 4, Figure 5). When NBPT was combined with liquid urea, the total loss in seven days was 29.0%, 24.6%, 22.8%, and 20.4% from the 0.125, 0.25, 0.5, and 1% treatment, respectively (Figure 4). Total loss of N in seven days at PPD 0.5% was 32.8%, 26.7% loss at 1% PPD, and 24.2% loss at 2% PPD (Figure 5).

Percentage inhibition of NH$_3$ volatilization in seven days was 41.8%, 50.7%, 54.2%, and 59.2% at the 0.125, 0.25, 0.5, and 1% NBPT rate, respectively (Figure 6). The PPD treatment reduced NH$_3$ volatilization 34.3, 46.5, and 50.1% at the 1, 2, and 3% rates, respectively (Figure 6). The results indicate that the NBPT is approximately four times as effective as PPD under the conditions established in this study.
Field and growth chamber studies indicate that the urease inhibitors NBPT and PPD have potential for increasing N use efficiency of urea-N applied as a liquid fertilizer to Kentucky bluegrass by reducing ammonia volatilization. The NBPT is the most effective of the two materials and both deserve further evaluation as fertilizer amendments. ATS, KCl, and MgCl₂ were relatively ineffective in reducing ammonia volatilization.


Table 1. The effect of urease inhibitors and cationic materials on NH₃-N volatilization following fertilization of Kentucky bluegrass turf with liquid urea at 49 kg N ha⁻¹ (1 lb N/1000 ft²) in the field test

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Days after treatment</th>
<th>Total N volatilized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>Control</td>
<td>2.9</td>
<td>4.1</td>
</tr>
<tr>
<td>PPD 1%</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>1.2</td>
</tr>
<tr>
<td>NBPT .5%</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>1.2</td>
</tr>
<tr>
<td>ATS 5%</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>2.4</td>
</tr>
<tr>
<td>K⁺ 5%</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>2.3</td>
</tr>
<tr>
<td>Mg⁺⁺ 5%</td>
<td>2.8</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>2.1</td>
</tr>
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</table>
Table 2. The analysis of variance for the loss of NH$_3$-N as affected by urease inhibitors PPD and NBPT in the growth chamber test

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replications</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Inhibitors treated</td>
<td>7</td>
<td>49.73**</td>
</tr>
<tr>
<td>Error A</td>
<td>21</td>
<td>0.64</td>
</tr>
<tr>
<td>Day measured</td>
<td>6</td>
<td>10.87**</td>
</tr>
<tr>
<td>Inhibitor X day measured</td>
<td>42</td>
<td>8.46**</td>
</tr>
<tr>
<td>Error B</td>
<td>144</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**Significant at the 0.01 probability levels.
Figure 1. Equipment used for the field measurement of ammonia volatilization
1. Air Compressor
2. Reserve Tank
3. Valve
4. Regulator
5. Filter
6. Manifold
7. Plexiglass Chamber and Steel Base
8. Air Inlet
9. To Ammonia Trap
Figure 2. Ammonia trapping system used for the growth chamber test
Figure 3. Percentage inhibition of volatilization of urea-N as NH$_3$ by urease inhibitors and cationic materials from the field measurement.

Liquid urea was applied at the rate of 49 kg ha$^{-1}$ (1 lb N/1000 ft$^2$).
Figure 4. Effect of NBPT on NH$_3$-N loss and percentage inhibition of NH$_3$ volatilization from the growth chamber test.

Liquid urea was applied at the rate of 49 kg ha$^{-1}$ (1 lb N/1000 ft$^2$).
LSD .05 = 2.2

- NBPT .125%
- NBPT .25%
- NBPT .5%
- NBPT 1%

LSD .05 = 1.5

- CONTROL
- NBPT .125%
- NBPT .25%
- NBPT .5%
- NBPT 1%
Figure 5. Effect of PPD on $\text{NH}_3$–N loss and percentage inhibition of $\text{NH}_3$ volatilization from the growth chamber test. Liquid urea was applied at the rate of 49 kg ha$^{-1}$ (1 lb N/1000 ft$^2$).
Figure 6. Percentage inhibition of volatilization of urea-N as NH$_3$ by PPD and NBPT in the growth chamber test.

Liquid urea was applied at the rate of 49 kg ha$^{-1}$ (1 lb N/1000 ft$^2$).
The effectiveness of the urease inhibitors phenylphosphorodiamidate (PPD), N-(n-butyl) thiophosphoric triamide (NBPT), and ammonium thiosulfate (ATS), and the cationic materials potassium (K\(^+\)) and magnesium (Mg\(^{2+}\)) as fertilizer amendments for increasing urea-N efficiency was evaluated by measuring the effect of these compounds on growth response and NH\(_3\) volatilization following application of urea to Kentucky bluegrass (Poa pratensis L.) turf. The first test for measuring the growth response conducted in growth chambers was a screening trial to evaluate PPD and MgCl\(_2\) in combination with four rates of N at two temperatures. Foliar burn was affected by N levels, PPD and MgCl\(_2\) treatments. Clipping yields were affected by temperature, N levels, and PPD and MgCl\(_2\) treatment. Turf treated with Mg\(^{2+}\) at 25% of the weight of N reduced foliar burn more than turf receiving the other treatments. This effect was more evident in low temperature than high temperature. The average fresh weight of clippings in pots treated with PPD increased at both temperature treatments.

The three-year growth response test in the field included liquid urea (10%) applied monthly in June through September in 1984 through 1986 with urease inhibitors PPD, NBPT, and ATS, and cationic materials KCl and MgCl\(_2\). The data obtained showed that the cations Mg\(^{2+}\) and K\(^+\) reduced foliar burn and increased visual turf quality with low concentrations under mild climatic conditions. The urease inhibitors PPD and NBPT significantly increased clipping yield across most application dates.
The fresh weight of clipping yield varied with month of application, and
the effect of PPD, and NBPT on percentage yield increase was greatest in
heat stress periods. Clipping yield response also varied among the weeks
following application. Yield increase showed a maximum in the first week
at the 2% rate of PPD, in the second and third weeks at the 0.5% rate of
NBPT, and in the fourth week at the 1 and 2% NBPT rates. Residual
responses to urea-N lasted longer at the higher rates of NBPT.

The NH₃ volatilization test included field and growth chamber
measurement. The chemical compounds used in the field measurement of NH₃
volatilization included NBPT, PPD, ATS, K⁺, and Mg²⁺ with three rates
each. Total N loss through NH₃ volatilization from the field measurement
in the 4 days following treatment was 18.5% of the applied N (49 kg ha⁻¹)
in the control (N alone). When NBPT was combined with liquid urea, the
total loss of urea-N as NH₃ in four days was 7.0%, 6.9%, and 5.6% at the
0.5, 1, and 2% NBPT rates, respectively. The total loss of N in four
days from PPD treated plots was 10.4%, 7.9%, and 7.2% loss at 1, 2, and
3% PPD rates, respectively. These figures represent a percentage
inhibitions of NH₃ volatilization in four days of 62.6%, 62.9%, and 69.6%
with the three rates of NBPT, and 43.8%, 57.3%, and 61.1% with the three
rates of PPD. Application of ATS and cationic materials K⁺ and Mg²⁺
resulted in similar trends of volatilization to those of the control.
The effectiveness of the materials on the reduction of NH₃ volatilization
following fertilization with urea decreased in the order NBPT > PPD >>
ATS > K⁺ > Mg²⁺.

The treatments used in the growth chamber measurement included four
rates of NBPT and three rates of PPD. Accumulative N loss through NH$_3$
volatilization from the control (N alone) was 49.9% of applied urea-N at
the end of the seventh day. Peak NH$_3$ loss occurred the first day after
applications without combination of urease inhibitors, however, the peak
occurred in the second day when the urea was combined with urease
inhibitors. When NBPT was combined with liquid urea, the total loss of
urea-N as NH$_3$ in seven days was 29.0%, 24.6%, 22.8%, and 20.4% at the
0.125, 0.25, 0.5 and 1% NBPT, respectively. Total loss of N in seven
days from PPD treatments was 32.8%, 26.7%, and 24.2% at the 0.5, 1, and
2% rates, respectively. Percentage inhibition of NH$_3$ volatilization as
compared with the control was 41.8%, 50.7%, 54.2%, and 59.2% with 0.125,
0.25, 0.5, and 1% NBPT, respectively. The PPD treatments reduced NH$_3$
volatilization 34.3, 46.5, and 50.1% at the 0.5, 1, 2% PPD rates,
respectively.

The results reported here indicate that the urease inhibitors NBPT
and PPD have potential for increasing N use efficiency of urea-N applied
as a liquid fertilizer to Kentucky bluegrass by reducing ammonia
volatilization. NBPT was the most effective of the two materials in
these studies and they both deserve further evaluations as fertilizer
amendments in the use of urea fertilizer.
ADDITIONAL LITERATURE CITED


27:175-180.


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