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## UREA NITRICPHOSPHATE FOR COOL-SEASON GRASS PRODUCTION

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**ABSTRACT:** Significant losses of nitrogen (N) can occur via volatilization of ammonia ( $\text{NH}_3$ ) when non-incorporated broadcast applications of urea or urea-containing fertilizers are made. This study was conducted to determine the efficacy of urea nitricphosphate (UNP) as an N and phosphorus (P) source for cool-season grasses and to evaluate  $\text{NH}_3$  volatilization potential of UNP as compared to urea under laboratory conditions. A three-year field study compared UNP to ammonium nitrate (AN) and urea at 56 and 112 kg N/ha for tall fescue (*Festuca arundinacea* Schreb.) and smooth brome (*Bromus inermis* Leyss.). Brome yields were significantly higher from UNP as compared to urea for one of the three years. No such differences occurred with fescue. Nitrogen uptake was significantly higher from UNP as compared to urea for one year each for brome and fescue. Phosphorus uptake by brome was significantly higher from UNP as compared to urea for two years. Laboratory incubation studies showed significantly lower  $\text{NH}_3$  volatilization from UNP than from urea after seven days, but no significant differences after 14 days. The delay in  $\text{NH}_3$  volatilization was due to the diffusion and subsequent hydrolysis of urea immediately below the soil zone initially influenced by the UNP. The reduction in  $\text{NH}_3$  volatilization at the early time could partially be attributed to an inhibition of urea hydrolysis and

significantly lower soil pH values for UNP as compared to urea in the upper 30 mm of soil cores. The general conclusion from the field and laboratory work was that UNP is a suitable N source for cool-season grasses, with the primary potential benefit being delayed  $\text{NH}_3$  volatilization as compared to urea.

## INTRODUCTION

Production and use of urea-containing fertilizers have increased steadily in the United States in recent years (1,6). From a fertilizer production viewpoint, a variety of reasons explain this trend, including a high N analysis, ease of handling for the finished products, and efficiency in manufacturing.

From a fertilizer use viewpoint, several potential problems have been associated with urea (3). Loss of N via  $\text{NH}_3$  volatilization is a significant problem when surface applications of urea or urea-containing fertilizers are made. This problem is most pronounced with established stands of perennial grasses, for which methods known to reduce  $\text{NH}_3$  volatilization, including incorporation or subsurface banding, are impossible or impractical. A study with tall fescue showed that 99% of the urea-N in a urea-ammonium nitrate solution could be accounted for with a knifed application as compared to only 77% accounted for with a surface application (13). The urea-N not accounted for was most likely lost via  $\text{NH}_3$  volatilization.

One approach to reducing the  $\text{NH}_3$  volatilization potential of urea-containing fertilizers has been to mix urea with acid coproducts to reduce microsite pH (4,15). Urea nitricphosphate (UNP) is such a product and is produced by solubilizing phosphate ore with nitric acid ( $\text{HNO}_3$ ) and then adding urea to the acidulate (2). Fertilizer grades vary slightly. An added benefit associated with UNP is that it allows solubilization of phosphate ore without the undesirable production of phosphogypsum.

Little information has been published on UNP, particularly field data. A UNP material with a fertilizer grade of 23-5-0 (N:P:K) and 74% of the N present as urea was studied under laboratory conditions (5). For three noncalcareous soils, the volatilization of  $\text{NH}_3$  was significantly less from UNP than from urea, when considered on the basis of equivalent total N rate or equal urea-N rate. For one calcareous soil and another limed noncalcareous soil, no differences occurred in

NH<sub>3</sub> volatilization when equal rates of urea-N were applied as UNP or as straight urea. This study also determined that the urea in UNP could diffuse away from the point of application and be hydrolyzed in an area of soil not acidified by the fertilizer material. Thus, NH<sub>3</sub> volatilization was delayed but not entirely prevented.

Significantly lower dry matter accumulation by sweet corn grown under greenhouse conditions was reported when comparing surface applied to incorporated UNP for two out of three UNP materials (14). Ammonia volatilization was assumed to be the reason for the inferior performance of the broadcast UNP.

The purpose of this study was to evaluate UNP as an N and P source for tall fescue and smooth bromegrass under field conditions and to investigate the NH<sub>3</sub> volatilization potential and changes in soil pH with depth from surface broadcast applications of UNP.

## MATERIALS AND METHODS

The UNP material was supplied by the Tennessee Valley Authority (TVA), Muscle Shoals, AL and had a fertilizer grade of 27-4-0 (N:P:K). The nitrogen was present as 64% urea-N, 30% NO<sub>3</sub>-N, and 6.0% NH<sub>4</sub>-N. A solution containing 1000 mg UNP/L had a pH of 3.2.

Two separate field experiments were conducted at the North Agronomy Farm at Kansas State University in Manhattan, KS. Both sites were located in areas mapped as a Wymore silty clay loam (Fine mortmorillonitic, mesic aquic Argiudoll). One site was on an established tall fescue stand, and the N sources were UNP, urea conditioned with formaldehyde, urea conditioned with Ca lignosulfonate (urea-LS, supplied by TVA), and ammonium nitrate (AN). Note that formaldehyde and Ca-lignosulfonate are conditioning agents added to harden urea granules and that these are not slow release N sources. The second site was on an established stand of smooth bromegrass, using the same N sources except for the urea-LS source. Soil pH was (1:1, soil-to-water) 6.3 and 7.0 at the brome and fescue sites, respectively.

The experimental design at each site was a randomized complete block with four replications. Each N source was applied at the rates of 56 and 112 kg N/ha. These rates are typical for hay production from cool-season grasses in the Central

Plains region of the United States (10). All N treatments were made as surface broadcasts. Phosphorus as triple superphosphate was also surface broadcast on the urea, urea-LS and AN treatments to balance P applications. Two check treatments were included. One did not receive any N or P (check), and the other received P at a rate equivalent to that applied with 112 kg N/ha as UNP (check + P). Plots were 2.5 by 5.0 m in size.

Treatments were applied in early March in 1988, 1989, and 1990. In 1988 and 1990, normal spring rainfall allowed harvests in late May. Below average rainfall during portions of 1988 and 1989 resulted in poor growth, and a May 1989 harvest was not taken. Adequate late summer rainfall during that year stimulated fall growth, however, and a harvest was made on 11 October 1989. A flail-type harvester was used for plant harvests. Surface soil samples (0-15 cm) were taken in fall 1989. Bray P1-extractable P was determined according to standard methods (11). Nitrogen and P concentrations in forage tissue were determined with an autoanalyzer after digestion in sulfuric acid ( $H_2SO_4$ ) and hydrogen peroxide [ $H_2O_2$ ] (16).

Ammonia volatilization potential for each N source was assessed by placing 80 g of soil at 200 g/kg gravimetric water content in a 250-mL square glass bottle and surface applying finely ground fertilizers at a rate of 224 kg N/ha. The N application rate was higher than that used in the field studies due to problems of excessive variability associated with using 112 kg N/ha. Three replications of representative soil samples from the check + P treatment at each site were used. Sponges moistened with a mixture of phosphoric acid and glycerol (to trap  $NH_3$ ) were placed in the mouths of the bottles, which were stored in sealed glass chambers. Humidified, ammonia-free air was passed through the chambers at a flow rate of approximately 1 L/min (total chamber volume was 38 L). Bottles were destructively sampled at 7 and 14 d. Ammonium was extracted from the sponges with two 40 ml aliquots of 1M potassium chloride (KCl). This procedure is a modification of one presented previously (7). Unfertilized controls were included to correct for background  $NH_3$  emissions. The incubation conditions were such that  $NH_3$  volatilization was likely maximized. This was done to determine the maximum relative differences in  $NH_3$  volatilization potential between N sources. Ammonia volatilization under field conditions would probably be different;

however, it is difficult to measure  $\text{NH}_3$  volatilization in the field and it is difficult to reproduce field conditions in the laboratory.

The effect of N sources on soil pH at various depths was assessed after surface applications of finely ground fertilizers were made to soil cores. The cylinders were made of polyvinyl chloride (PVC) tubing (5.08 cm i.d.). A moveable piston served as the bottom of the core. The piston was used to push the sample out the top of the cylinder. Soil cores were prepared by packing moist soil (200 g/kg gravimetric water content) to a uniform bulk density. The soil samples, N application rate, incubation conditions, number of replicates, and sampling times were identical to those used for the volatilization study. At each sampling time, the cores were sampled from 0 to 10 mm at 2 mm intervals, from 10 to 20 mm at 5 mm intervals, and from 20 to 50 mm at 10 mm intervals. Soil pH was determined on 1:1 soil-to-water pastes.

## RESULTS AND DISCUSSION

### Field Studies

Attempts to combine yield, forage N and P concentration, and N and P uptake over years were largely unsuccessful due either to significant treatment by year or rate by year interactions. Therefore, the data will be discussed on a yearly basis.

Forage yields are given in Table 1. There were no significant responses to the addition of P alone. Bray extractable-P levels for the check treatments were 19 and 12 mg P/kg for the brome and fescue site, respectively. Previous work with brome in Kansas has demonstrated that yield responses to P are not likely with available P levels as high as these (12). With one exception, there were no significant differences in yield among N sources at a given N rate. The exception was the 1988 fescue harvest, in which 112 kg N/ha as urea gave a significant lower yield than the same rate of N from AN.

In 1988 and 1990, yields generally increased with increasing N rate. In 1989, some significant yield increases were seen between the 56 kg N/ha and check treatments, but increasing the N rate to 112 kg N/ha either resulted in no further yield increases or declines in yield. This was mostly likely due to the exceptionally dry conditions during late 1988 and early 1989. Total precipitation between August 1988 and July 1989 (the year prior to the return to average or above

TABLE 1. Forage Yields for 1988-90.

Treatment	Fescue			Brome		
	1988	1989	1990	1988	1989	1990
	----- kg/ha -----			----- kg/ha -----		
Check	2608	1789	1596	1173	2096	1692
Check +P	2530	2104	1569	1210	2339	1747
56 kg N/ha						
AN	3592	2484	3935	2143	3427	5001
Urea	4044	2740	3371	1903	3081	4630
Urea-LS	3446	2999	3165	-- <sup>a</sup>	--	--
UNP	3524	2734	4453	2146	3006	5149
112 kg N/ha						
AN	4919	2311	6123	2654	3373	6642
Urea	3536	2265	4394	2564	3413	6199
Urea-LS	4112	1878	6196	--	--	--
UNP	4210	1782	5312	2826	3540	6763
LSD (0.05)	1167	1140	1869	521	699	814
<u>Contrasts</u>						
UNP vs AN	NS	NS	NS	NS	NS	NS
UNP vs urea	NS	NS	NS	NS	NS	e <sup>b</sup>
AN vs urea	NS	NS	e <sup>c</sup>	NS	NS	NS

<sup>a</sup>Not evaluated at the brome site; <sup>b</sup> P < 0.064; <sup>c</sup> P < 0.086

average precipitation) was 425 mm as compared to the long-term average of 835 mm.

Single degree of freedom contrasts indicated that there were no significant differences in forage yields when UNP was contrasted with AN for fescue or brome for all three years. Similar results were obtained for the UNP versus urea contrast with the exception of the 1990 brome yields. Here the UNP source yielded significantly higher (5956 versus 5415 kg N/ha) when contrasted against urea. The 1990 fescue yields were also significantly higher when the AN source was contrasted against urea (5029 versus 3883 kg N/ha).

Fescue forage N concentrations were not significantly influenced by the addition of P alone or by N source at the 56 kg N/ha rate (Table 2) for all three years. Similarly, N concentrations were not significantly influenced by N source at the 112 kg N/ha rate in 1988. Forage N concentrations were significantly higher for the 112 kg N/ha as AN treatment as compared to similar rates of either ureas in 1989 and as compared to a similar rate of urea in 1990.

Single degree of freedom contrasts demonstrated that UNP produced significantly higher N concentrations in fescue tissue when compared to AN in 1988 (15.1 versus 15.0 g N/kg) and to urea in 1990 (15.1 versus 13.2 g N/kg). The AN versus urea contrast was also significant for 1989 (17.9 versus 16.7 g N/kg) and 1990 (15.8 versus 13.8 g N/kg).

Brome forage N concentrations were not significantly influenced by the addition of P alone in 1988 and 1990 (Table 2). In 1989, however, N concentrations were significantly higher for the check treatment as compared to the check +P treatment. This is most likely due to a dilution effect from the slightly higher yields for the check +P treatment (Table 1) under N limiting conditions. No significant differences in N concentrations were found between N sources at 56 kg N/ha for all three years and at 112 kg N/ha in 1988 and 1989. For 1990 the urea and UNP source at 112 kg N/ha had significantly higher N concentrations as compared to AN. A similar result was obtained with the single degree of freedom contrasts in the UNP versus AN comparison (15.7 versus 14.8 g N/kg).

Nitrogen uptake by fescue was not significantly affected by the addition of P alone during 1988-1990 (Table 3). Likewise, during 1988-1990 there were no significant differences in N uptake between N sources at 56 kg N/ha and between



TABLE 2. Forage Tissue N Concentrations for 1988-1990.

Treatment	Fescue			Brome		
	1988	1989	1990	1988	1989	1990
	----- g/kg -----			----- g/kg -----		
Check	11.9	14.5	12.3	15.3	19.1	13.8
Check +P	12.3	14.7	11.4	14.0	16.7	13.6
56 kg N/ha						
AN	14.6	16.7	13.8	17.9	19.7	14.1
Urea	13.1	15.9	12.5	17.8	20.0	13.5
Urea-LS	14.1	16.5	12.3	-- <sup>a</sup>	--	--
UNP	13.3	15.8	13.8	18.3	20.3	14.4
112 kg N/ha						
AN	15.4	19.0	17.7	21.1	22.1	15.4
Urea	16.9	17.5	13.8	21.9	22.1	17.0
Urea-LS	16.6	17.4	16.4	--	--	--
UNP	16.8	18.5	16.3	21.5	22.5	16.9
LSD (0.05)	2.2	1.3	1.9	1.6	2.1	1.1
<u>Contrasts</u>						
UNP vs AN	e <sup>b</sup>	NS	NS	NS	NS	* <sup>c</sup>
UNP vs Urea	NS	NS	** <sup>d</sup>	NS	NS	NS
AN vs Urea	NS	*	**	NS	NS	NS

<sup>a</sup> Not evaluated at the brome site; <sup>b</sup> P < 0.078; <sup>c</sup> P < 0.05; <sup>d</sup> P < 0.01

TABLE 3. Nitrogen Uptake for 1988-1990.

Treatment	Fescue			Brome		
	1988	1989	1990	1988	1989	1990
	----- kg/ha -----			----- kg/ha -----		
Check	26.8	22.4	17.1	15.7	34.7	20.4
Check +P	27.8	26.9	15.6	14.9	33.6	20.6
56 kg N/ha						
AN	46.4	35.8	47.4	33.3	54.9	61.2
Urea	45.6	37.0	38.0	29.6	53.8	54.4
Urea-LS	43.0	42.6	34.3	-- <sup>a</sup>	-	-
UNP	40.2	38.1	48.6	33.9	52.6	64.8
112 kg N/ha						
AN	66.0	37.0	94.5	49.1	66.1	88.9
Urea	51.6	34.7	53.2	48.7	66.1	92.1
Urea-LS	59.6	28.0	89.3	-	-	-
UNP	60.7	29.1	77.2	53.0	69.4	100.1
LSD (0.05)	14.8	15.7	26.0	7.8	11.2	9.4
<u>Contrasts</u>						
UNP vs AN	NS	NS	NS	NS	NS	* <sup>b</sup>
UNP vs urea	NS	NS	e <sup>c</sup>	NS	NS	** <sup>d</sup>
AN vs urea	NS	NS	**	NS	NS	NS

<sup>a</sup> Not evaluated at brome site; <sup>b</sup> P < 0.05; <sup>c</sup> P < 0.064; <sup>d</sup> P < 0.01

sources at 112 kg N/ha for 1988 and 1989. In 1990, AN at 112 kg N/ha had significantly higher N uptake as compared to both urea and urea-LS but was not significantly different than UNP. Single degree of freedom contrasts indicated that N uptake by UNP was significantly higher as compared to urea (62.9 versus 45.6 kg N/ha) for 1990. Similarly, the AN versus urea contrast was significant in 1990 (71.0 versus 45.6 kg N/ha).

There were no significant differences in N uptake by brome during 1988-1990 due to the addition of P alone (Table 3). There were also no significant differences in N uptake between N sources at a given N rate for 1988 and 1989. In 1990, N uptake from UNP was significantly higher than urea at 56 kg N/ha and significantly higher than AN at 112 kg N/ha. Single degree of freedom contrasts for 1990 also noted the significantly higher N uptake from UNP as compared to AN (82.5 versus 75.1 kg N/ha) or urea (82.5 versus 73.3 kg N/ha).

The field data are supportive of previous work with brome or fescue, in which surface applications of urea or urea-containing fertilizers were inferior to sub-surface applications of the same materials or to ammonium nitrate, presumably because of volatilization losses of  $\text{NH}_3$  (8,9,13). The performance of the UNP material was comparable to that of AN, with both generally being superior to urea. Where significant differences or contrasts occurred, UNP means were always higher. The major advantage of UNP would appear to be N uptake, which would translate into higher apparent nitrogen use efficiency for UNP as compared to urea or AN some years. Thus, UNP is a suitable N source for brome and fescue.

Forage P concentrations were not significantly influenced by N rate or source for brome or fescue for all three years (data not shown). Significant differences in P uptake, therefore, closely paralleled differences in yields (Table 1). Single degree of freedom contrasts indicated that P uptake by UNP was significantly higher than urea for brome during 1988 (5.2 versus 4.6 kg P/ha) and 1990 (12.6 versus 11.5 kg P/ha).

#### **Ammonia Volatilization and Soil pH Effects**

Ammonia volatilization, expressed as a percent of the total N applied, was significantly lower from UNP than from urea or urea-LS at one week for soil samples taken from both locations and at two weeks for soil samples taken from the fescue location (Table 4). No significant differences in  $\text{NH}_3$  volatilization

TABLE 4. Ammonia Volatilization With Time From the Surface Application of the N Sources to Soil Samples Taken From Both Field Locations. Nitrogen Was Applied at a Rate Equivalent to 224 kg N/ha.

N source	Brome site	
	1 Week	2 Weeks
	-----% of N applied-----	
Urea	14.5	10.6
Urea-LS	13.7	11.2
UNP	4.6	10.8
AN	0.5	2.8
LSD (0.05)	2.1	1.2
	Fescue site	
Urea	9.7	13.0
Urea-LS	12.0	13.9
UNP	2.0	8.2
AN	0.3	1.0
LSD (0.05)	3.0	2.8

occurred among UNP, urea, and urea-LS at two weeks for soil samples taken from the brome site. Two factors might have played a role in the reduced NH<sub>3</sub> volatilization from UNP. First, applying the fertilizer materials on an equivalent total N basis resulted in a lower urea-N application for the UNP than for the urea. This reduced urea-N application rate could reduce the amount of NH<sub>3</sub> volatilized. Second, the acidic nature of the UNP would reduce the fraction of ammoniacal N that would be present as NH<sub>3</sub> and could also inhibit urea hydrolysis (4).

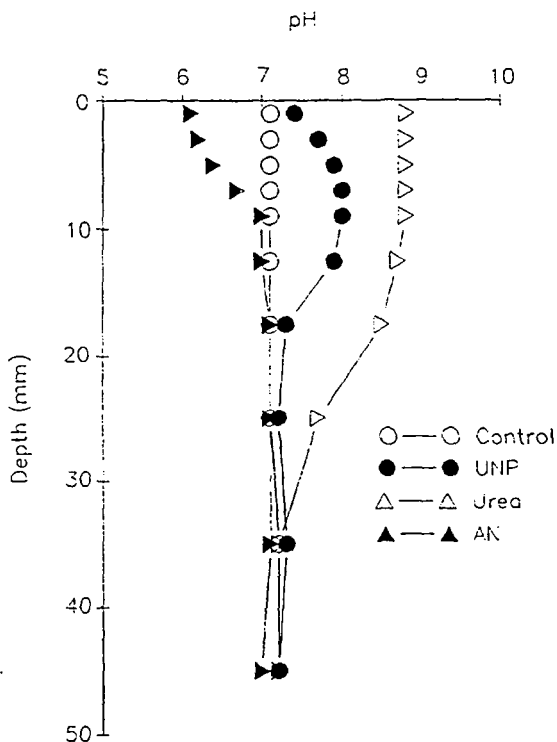


FIGURE 1. Soil distribution with depth one week after a 224 kg N/ha fertilizer application to a sample of the surface horizon of a Wymore silty clay loam.

The  $\text{NH}_3$  volatilization data in Table 4 is expressed as a fraction of the total N applied. Alternatively,  $\text{NH}_3$  volatilization could be expressed as the percentage of urea-N applied for UNP and the ureas since the urea is the  $\text{NH}_3$  source. Similar rates of  $\text{NH}_3$  volatilization were reported from UNP when comparing 100 kg N/ha (74 kg urea-N/ha) to 135 kg N/ha (100 kg urea-N/ha) applied to noncalcareous soils (5). In this study, 7.2 and 3.1% of the urea-N from UNP was volatilized for the brome and fescue site soil samples, respectively, after one week. These values

are significantly lower ( $P < 0.05$ ) than those for urea and urea-LS. If the reduced urea-N application rate was the sole reason for the reduced  $\text{NH}_3$  volatilization when comparing UNP to urea, then there would be no difference in  $\text{NH}_3$  volatilization between these sources when expressed as a percent of urea-N. A similar situation did not exist at two weeks, however, when urea-N volatilization from UNP was similar or higher than that from urea or urea-LS. It is apparent that the reduced urea-N application rate for UNP as compared to urea or urea-LS could only be partially responsible for the reduced  $\text{NH}_3$  volatilization after one week.

The relative differences in soil pH by depth as influenced by N source and time of sampling were similar for soils taken from the two locations, so only a representative set of data after a one week incubation for soil samples taken from the fescue site is presented (Figure 1). The curve for the urea-LS source was very similar to that of the urea source, and it was omitted for the sake of clarity. Data such as these have not been published previously for UNP. The UNP source had a significantly lower pH ( $P < 0.05$ ) than urea at all depths less than 30-40 mm and a significantly higher pH ( $P < 0.05$ ) than the unfertilized control at all depths less than 10-15 mm. This reduction in pH for the UNP source as compared to urea would also act to reduce volatilization losses of N in comparisons of the two sources.

When the influence of UNP applications on soil pH with depth and time is examined, it is clear the benefits of the acidic nature of the material were short-lived (Figure 2). In particular, the increase in pH after two weeks in the range of depths from 10 to 30 mm was likely due to the diffusion and subsequent hydrolysis of urea immediately below the zone initially influenced by the UNP. Similar results were reported for a UNP material (5) and for urea phosphate (15). The increases in soil pH with time and the apparent urea hydrolysis between one and two weeks with the UNP probably were causative factors in the steady increases in  $\text{NH}_3$  volatilization with time (Table 4).

The remaining issue is whether or not the UNP material is acidic enough to inhibit urea hydrolysis. This effect was noted in studies with urea phosphate (4,15). Mixed results were reported with regard to urea hydrolysis rates from UNP (5). For one soil with an initial pH of 5.5 there were significantly higher amounts of unhydrolyzed urea remaining from UNP as compared to straight urea

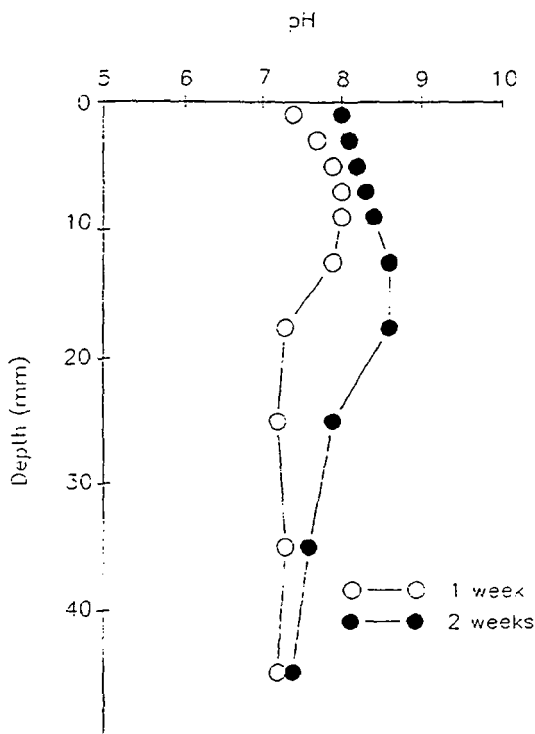


FIGURE 2. Soil pH distribution with depth and time after a UNP application equivalent to 224 kg N/ha to a sample of the surface horizon of a Wymore silty clay loam.

after seven days. Another soil with an initial pH of 6.0 that was evaluated in a limed and unlimed state had no unhydrolyzed urea remaining after a seven day incubation. In another study, detectable concentrations of urea were not found after a 14 d incubation with three different UNP materials (14).

The increase in volatilized N (Table 4) and the increase in soil pH from 10 to 35 mm (Figure 2) between seven and 14 days for UNP suggests that a substantial amount of urea was hydrolyzed in this time period. Comparable increases in

volatilized N or soil pH (data not shown) were not seen with urea from seven to 14 days. This further suggests that urea hydrolysis was inhibited from the UNP source.

Reductions in N volatilization from UNP as compared to urea at one week are likely the net result of several processes. No direct evidence of a reduction in  $\text{NH}_3$  volatilization due to the lower urea-N application rate from UNP applications as compared to urea was obtained and this possibility cannot be discounted. Significantly lower soil pH values in the upper 30 mm of soil for UNP as compared to urea would also reduce the fraction of ammoniacal N present as  $\text{NH}_3$  from the urea that did hydrolyze. Additionally, the data suggests that urea hydrolysis from UNP was inhibited. These processes do not aid in reducing  $\text{NH}_3$  volatilization as the urea in UNP diffuses to soil depths unaffected by the initial UNP application.

### CONCLUSIONS

Field evaluations of UNP as a N source for cool-season grasses generally indicated that its performance was comparable to that of AN and superior to that of urea or urea-LS. Single degree of freedom contrasts indicated that, when significant differences between UNP and the remaining N sources occurred for yield, forage N concentration or N uptake, the UNP means were always higher. Due to limited forage responses to P, it is difficult to evaluate UNP as a P source. However, significantly higher P uptake by brome when UNP was contrasted against urea occurred during two years.

Laboratory incubation data indicated that  $\text{NH}_3$  volatilization from UNP as compared to urea was delayed but not prevented entirely. Ammonia volatilization from UNP at the longer incubation time was due to diffusion and hydrolysis of urea below the zone initially influenced by UNP. Inhibition of urea hydrolysis, a lower soil pH in the reaction zone of UNP as compared to urea and a lower urea-N application rate may have contributed to the reduction in  $\text{NH}_3$  volatilization from UNP. Results from the laboratory studies cannot be extrapolated directly to the field studies. The data does suggest, however, that delayed  $\text{NH}_3$  volatilization is a primary benefit of UNP. The length of time between a surface broadcast application of a N fertilizer and a rainfall or irrigation event sufficiently intense to move urea



into the soil so that  $\text{NH}_3$  volatilization cannot occur is the period of susceptibility for  $\text{NH}_3$  volatilization. The delayed  $\text{NH}_3$  volatilization from UNP could lead to lower volatilization losses for UNP during some growing seasons.

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