Influence of Nitrogen Fertilizer Rate on the Uptake of ^{15}N Labeled Urea and Ammonium Sulfate by Soft Red Winter Wheat in the Presence and Absence of *Poa annua*.

B.R. Griggs, R.J. Norman and W. Johnson

INTRODUCTION

Many Arkansas farmers can increase yields and profits by increasing the efficiency of nitrogen (N) uptake in winter wheat. Rates that are suboptimum have been shown to result in lower numbers of tillers and reduced grain yields, while excessive N fertilization leads to lodging, yield reduction, delays harvesting, and potential negative environmental impacts (Baethgen and Alley, 1989; Gillelan and Macknis, 1983). Low N efficiency can be attributed to losses from NH_3 volatilization, denitrification, leaching, immobilization, and N loss from the wheat plant (Sharpe et al, 1988).

In most regions of Arkansas, N fertilizer application is recommended for both early and late planted wheat or where wheat is following a previous grain crop. The two most common N fertilizers applied to wheat are urea and ammonium sulfate. Urea is much cheaper than ammonium sulfate, but is more prone to loss via ammonia volatilization. Questions have been asked about whether the additional cost of ammonium sulfate justified the return in increased N uptake and decreased N loss.

There is a direct correlation between the amount of N made available to crops from urea and ammonium sulfate and the transformations that occur within the soil. Ammonium sulfate is a good fertilizer from the standpoint that it has a low hygroscopicity and is relatively stable chemically (Tisdale et al, 1993). In high pH soils ammonium sulfate can act as a mild acidulant due to reactions between the NH_4^+ (pKa 5.6 x 10^{-11}) and either water or OH^- ions in the soil whereby the ammonium molecule will donate an H^+ thereby reducing the soils pH (Brown et al, 199; Olson et al, 1971).

Urea fertilizer on the other hand can increase soil pH especially on or near the region where the fertilizer is placed. Urea reacts with the enzyme urease which catalyzes the hydrolysis of urea to form ammonium carbamate which is unstable and is rapidly transformed to NH_3 and CO_2 ($NH_2CONH_2 + H_2O$ —urease—> 2 NH_3 + CO_2). In most soils the NH_3 rapidly reacts with free protons in the soil to form NH_4^+ (Wilson, 1989; Eivazi, 1998). However, flooded or saturated soils tend to have lower urease activity due to the elevated solubility of reduced metals (Eivazi, 1998).

The nitrification-denitrification sequence in soils can lead to significant gaseous N losses, especially in soils that are characterized by alternating periods of dry followed by periods of flooding. Nitrification is the result of activity by *Nitrosomonas* and *Nitrobacter* bacteria, respectively, under strictly aerobic conditions Simply put, nitrification is the production of nitrate from reduced nitrogen compounds (NH_4^+) (Myrold, 1998) In the first step of this process *Nitrosomonas* oxidizes NH_4^+ to NO_2^- and then relatively quickly *Nitrobacter* oxidizes NO_2^- to NO_3^-. Nitrous oxide (N_2O) and H^+ may also be by products of the first step of ammonia oxidation. Under aerobic conditions the production of N_2O is minimal (less than 1%), however as oxygen availability decreases relatively more oxide is produced (Myrold, 1998).

Denitrification involves the reduction of NO_3^- and NO_2^- to gaseous forms such as N_2 and N_2O. This process is the result of anaerobic respiration by microbes which use the NO_3^- and NO_2^- as terminal electron acceptors (Brady and Weil, 1990; Myrold, 1998)

Ammonia volatilization is another mechanism by which soils may lose a significant amount of N, especially when ammonium and urea fertilizers are used. Soil factors can have a pronounced effect on both the rate and amounts of ammonia volatilization. The texture of a soil primarily determines the extent of water movement within the soil and if or how long an ion is attenuated (Vlek et al, 1979). Soil pH can have a detrimental effect on volatilization especially when N fertilizer is applied directly on the soil. Higher pH soils which lack an abundance of H^+ ions will slow the conversion NH_3 to NH_4^+ leaving more fertilizer in the gaseous state for a longer period of time.

Environmental factors that affect ammonia volatilization tend to revolve around moisture and wind relations. Moist ground conditions or high relative humidity cause increased hydrolysis of ammonia in the urea fertilizer at the ground surface where it is in direct contact with the air and can volatize quickly. However, rainfall also has the potential to transport the urea into the soil thereby reducing volatilization (Boumeester et al, 1985). Airflow rates tend to have a non linear relationship to volatilization. At high flow rates the air tends to lower the temperature of the soil surface thereby reducing volatilization (Katyl and Carter, 1989).

In many regions of Arkansas annual bluegrass (*Poa annua*) has been identified as a common winter weed problem. Currently, it is unknown whether the perceived decrease in N uptake by winter wheat in the presence of *Poa annua* is due to uptake by the *Poa annua* plant itself or increased ammonia volatilization due to the high levels of urease on the leaves of the *Poa annua*. If ammonia volatilization is the loss mechanism then ammonium sulfate would be superior as an N source for wheat when *Poa annua* is present. Defining the efficiency of urea-N and ammonium sulfate-N by wheat plants in both the presence and absence of *Poa annua* is necessary in identifying the best possible practice for N application in winter wheat. Only one ^{15}N study has been performed on winter wheat in Arkansas (Bashir et al, 1997) and it was conducted at Kibler, AR. This study found that wheat took the fertilizer up efficiently, but lost a significant amount during grain development. The results from this study needs to be verified in eastern Arkansas where wheat is grown.

The objective of this study were (i) to determine the uptake of ^{15}N labeled urea and ammonium sulfate by wheat in the presence and absence of *Poa annua* (ii) to determine the extent that these N fertilizers are lost via ammonia volatilization in the presence and absence of *Poa annua* (iii) and to determine the extent that these N fertilizers are taken up by *Poa annua*.

MATERIALS AND METHODS

The first year of the field experiment was conducted in 1999-2000 at the University of Arkansas Rice Research and Extension Center, Stuttgart, AR, on a Dewitt silt loam (Fine, smectitic, thermic Typic Albaqualf). The soil in the plow layer had a pH of 5.5 and a bulk density of 1.47g/cm^3. Pioneer 2580 was the variety selected because it is tolerant to Sencor®, a commonly used herbicide for the control of *Poa annua*. The wheat was drill seeded at a rate of 110 lbsN/A with a 7 inch row spacing on October 15, 1999 and emergence was recorded on October 25, 1999 with an emergence rate of 95%. Plot size was 63 inch by 48 inch, having nine rows. Urea and ammonium sulfate labeled with 2 atom % N was applied at rates of 0, 89, 134, and 179 kg N ha^{-1} in a split application on March3, 2000 and March 23,2000.

After each fertilizer application, ammonia volatilization was measured for 20 days. A clear plexiglass cylinder was driven approximately 15 cm into the soil and either ^{15}N labeled urea or ammonium sulfate equivalent to 134 kg N ha^{-1} was placed on the soil inside the cylinder. In three of the four replications of the 134 kg N ha^{-1} treatment a cylinder was placed between wheat rows and in the rows themselves. Ammonia was trapped in a foam rubber sorber that was impregnated with 20mL of 0 73M H_3PO_4 (33% glycerine) and the sorber was then extracted using a 50 mL solution of 2N KCl.

Plant sampling consisted of removing the above ground portion of the wheat plants from a two foot section of two interior rows at each sampling. Plant samples were taken at Feekes Growth Stage 8 -9 (flag leaf emergence) which represents the maximum N fertilizer accumulation in the plant when ^{15}N is used, and at Feekes growth stage 11, physiological maturity, for total N and ^{15}N uptake and partitioning. Soil samples were taken at each plant sampling by taking a 20 cm deep core within the area sampled to assess the amount of ^{15}N in both the organic and inorganic N soil fractions.

Total N for the plant samples was determined on a 0.2-g subsample by the permanganate-reduced Fe modification of the semimicro-Kjeldahl procedure (Bremmner and Mulvaney, 1982). Soil inorganic (exchangeable NH_4^+ and NO_3^- + NO_2^-)-N was determined on a 10-g subsample by the extraction-distillation procedure (Keeney and Nelson, 1982), soil total N on a 1-g subsample by permanganate-reduced Fe modification of the semimicro-Kjeldahl procedure. The distillation apparatus was cleaned between each sample by the duplicate aliquot technique to prevent ^{15}N cross contamination (Mulvaney, 1986).

Field preparation for the 2000-2001 winter wheat project was begun October 13, 2000. Pioneer 2580 (a Sencor® tolerant variety) was planted at the Rice Research and Extension Center in Stuttgart, AR and emergence was recorded on October 23, 2000. Immediately before the wheat was planted *Poa Annua* (annual bluegrass) was over-seeded in the appropriate plots and the wheat was planted at a rate of 110 lbs/a The first application of a split application for ^{15}N labeled urea and ammonium sulfate was applied February 19, 2001 and ammonia volatilization data was collected for three weeks. The 2nd application of ^{15}N labeled-fertilizer was applied on March 15, 2001 and ammonia volatilization will be recorded for three weeks

Sampling for the second year was conducted at flag leaf emergence (April, 13) and physiological maturity (May, 16) for total N and fertilizer N uptake, and total dry matter and grain yield.

RESULTS AND DISCUSSION

In the first year of this study cultivation to prepare the wheat seed bed completely eliminated the excellent stand of indigenous *Poa annua* within the research plots. Attempts to over seed the plots with *Poa annua* failed due to a very dry fall. Consequently, we decided to conduct the research on fertilizer N uptake *by Poa annua* and ammonia volatilization in the presence of *Poa annua* outside the wheat test plot area in an adjacent area with a good stand of indigenous *Poa annua*. *Poa annua* plots were sampled at the same times as the wheat plots and ammonia volatilization was carried out in the same manner. The data from these plots will represent an overabundance of the weed, but will give a worst case scenario for N uptake by the *Poa annua* and ammonia volatilization losses in the presence of *Poa annua*. Plant samples were taken at Feekes growth stage 10.5 instead of Feekes growth stage 9 to allow time for N fertilizer uptake.

AMMONIA VOLATILIZATION

Ammonia volatilization was highest for urea applied to wheat at both application times (Table 1). The first application shows decreased volatilization compared to the second most likely due to a soaking rainfall that occurred the night before and while the first N application was made. Ammonium sulfate showed < 1% ammonia volatilization of the N applied compared to urea, which varied significantly between bluegrass plots and wheat. Volatilization for wheat averaged 12% of the applied N compared to 2.7% for bluegrass. This could possibly indicate *Poa annua* has greater N uptake rates than wheat. The soil atmosphere in the wheat plots remained moist for a greater percentage of the time than that of the wheat and the grass had a more extensive fibrous root system that was in closer proximity to the fertilizer. Results from this preliminary data suggests, that the lack of N uptake by wheat in the presence of *Poa annua* is not due to greater ammonia volatilization losses, but rather that the *Poa annua* is competing quite effectively with the wheat for the N fertilizer; whether it is supplied by urea or ammonium sulfate.

Table 1. Ammonia volatilization for wheat and bluegrass with N applied in a split application as either N^{15}-labeled urea or ammonium sulfate at a rate of 134 kg ha^{-1}.

	1st Application		2nd Application		Total	
	Wheat	**Bluegrass**	**Wheat**	**Bluegrass**	**Wheat**	**Bluegrass**
N source	--------------------	----------	% of N applied	----------	----------	--------------------
Urea	10.76	2.16	13.12	3.3	12.0	2.73
AS	0.33	0.26	0.57	0.26	0.45	0.26
LSD(0.05)	†0.72		‡0.56			

†LSD(0.05) = least significant differences for plant x N-source interaction
‡LSD(0.05) = least significant differences for plant x N-source interaction

Poa annua

The research for *Poa annua* was conducted just outside the wheat plot area where there was an excellent stand of indigenous *Poa annua*. The data presented in Table 5 illustrates the total dry matter, N concentration, and total N uptake for *Poa annua* which received 134 kg N ha^{-1} as either urea or ammonium sulfate. *Poa annua* produces a substantial amount of dry matter anf the plant itself is approximately 3% N (Table 2). By Harvest 1 (Feekes GS 10.1), all of the N fertilizer should have been taken up by the *Poa annua* if there are any similarities between wheat and *Poa annua*. Thus, at just past flag leaf emergence the *Poa annua* had accumulated an average of 80 kg N ha^{-1} in total N and over 41% of the N added in fertilizer regardless of source. This suggests that *Poa annua* can compete quite effectively with wheat for N fertilizer.

Table 2. Total dry matter, total N uptake, and percent of N applied for bluegrass sampled at Feekes GS 10.1 in wheat with N^{15}-labeled urea or ammonium sulfate applied at a rate of 134 kg ha^{-1}.

	TDM	Total N Uptake	Fertilizer N Uptake
N Source	------kg ha^{-1}-------	------kg N ha^{-1}-------	----% of N applied----
Urea	2536	82.6	42.9
AS	2520	78 9	41.7
LSD0.05)	NS	NS	NS

WHEAT

Results for total dry matter, total N uptake and percent of N applied in the plant at Feekes GS 10.1 for winter wheat, all increased significantly with increased N fertilizer rate (Table 3). The differences between urea and ammonium sulfate are statistically insignificant, but there is a trend for ammonium sulfate to result in better N uptake compared to urea. This sampling date represents the period in which the wheat plant has its maximum concentration of fertilizer N and shows that uptake of fertilizer N in the wheat is only slightly higher than that of the bluegrass. At this date wheat with N fertilizer applied at a rate of 134 kg N ha^{-1} contains 45% of the applied N, 48% remained in the soil and the balance was lost primarily to ammonia volatilization.

Table 3. Total dry matter, total N uptake, and percent of N-fertilizer taken up by wheat at Feekes GS 10.1 when applied as either N^{15}-labeled urea or ammonium sulfate.

N Rate	TDM	Total N Uptake	Fertilizer N Uptake
kg N ha^{-1}	**kg ha^{-1}**	**kg N ha^{-1}**	**% of N applied**
0	5912	42	0
89	7035	74	48
134	7878	90	45
179	9628	113	43
$LSD_{(0.05)}$	484†	13‡	7§

† LSD(0.05) = least significant differences among N rates within a column for TDM
‡LSD(0.05) = least significant differences among N rates within a column for Total N uptake
§ LSD(0.05) = least significant differences among N rates within a column for % of N applied

At physiological maturity (Feekes GS 11.4) total dry matter and yield increased with increased fertilizer rate to the 134 kg N ha^{-1} level after which there was no increase (Table 4). There were no statistically significant differences between urea and ammonium sulfate but, ammonium sulfate did show a trend for increased yields at all N rates used. Nitrogen accumulation at maturity showed increased uptake with increasing rates to the134 kg N ha^{-1} level after which there was no increase resulting from additional N (Table 5). At this stage the bulk of the N taken up by the plant was located in the spikes. Other researchers have found similar results. Bashir et al (1997) in a 2-yr study found that from Feekes growth stage 10.5 to 11, spike and total above ground N increased while the straw N decreased significantly. Sharpe et al. (1988) also showed similar uptake amounts for the total above ground portion in wheat grown in a conservation-tilled system

Harvest index is a ratio of grain yield divided by the total aboveground dry matter yield (grain + straw). This type of data indicates if increasing N fertilizer rate is resulting in more grain to straw weight. The harvest index for the wheat increased when ammonium sulfate was the N source up until 134 kg N ha^{-1} was applied then showed no change when as much as 179 kg N ha^{-1} was applied. Urea resulted in slightly lower harvest indexes for each N rate compared to ammonium sulfate. In addition, the harvest index for the wheat increased as N rate increased only up to the 134 kg N ha^{-1} rate and then decreased as more N was applied as urea.

Table 4. Dry matter accumulation for wheat at Feekes GS 11.4 when N-fertilizer applied as either N^{15}-labeled urea or ammonium sulfate

		Dry Matter	
N Rate	Straw	Spikes	TDM
kg N ha^{-1}		--kg ha^{-1}--	
0	4770	4233	9003
89	6650	6648	13298
134	6768	6944	13742
179	6972	6122	13094
$LSD_{(0.05)}$	737†	492‡	988§

† LSD(0.05) = least significant differences among N rates within a column for Straw
‡ LSD(0.05) = least significant differences among N rates within a column for Spikes
§ LSD(0.05) = least significant differences among N rates within a column for TDM

Table 5. Total N accumulation by winter wheat at Feekes GS 11.4.

	Total N Accumulation		
N Rate	Straw	Spikes	TDM
kg N ha^{-1}	---------------------------------kg N ha^{-1}---------------------------------		
0	15	52	67
89	30	93	123
134	51	110	161
179	49	93	142
LSD$_{(0.05)}$	9†	20‡	16 §

† LSD(0.05) = least significant differences among N rates within a column for straw.
‡ LSD(0.05) = least significant differences among N rates within a column for Spikes
§ LSD(0.05) = least significant differences among N rates within a column for TDM

Data for the second year of the study looked at wheat responses with bluegrass grown in the plots with the wheat. The data for dry matter showed statistically significant differences between N rates but not N fertilizer sources, much as the first year. When averaged over bluegrass treatments (+ or - bluegrass) and N source the data shows increased total dry matter accumulation at both Feekes GS 9.1 and 11.4 and yield at maturity up to the 134 kg N ha^{-1} after which there is no response to added N (Table 6).

Table 6. Total dry matter accumulation (2001) by winter wheat at Feekes GS 9.1 and 11.4 averaged over N-source and Bluegrass treatments .

	Feekes 9.1	Feekes 11.4		
N Rate	TDM	Straw	Spikes	TDM
----kg N ha^{-1}----		--------------kg ha^{-1}-----------------		
0	2239	1904	2612	4516
89	3881	3837	4850	8687
134	5048	4006	5342	9348
179	5128	4365	5719	10084
†LSD$_{(0.05)}$	515	410	498	956

† LSD(0.05) = least significant differences among N rates in a column.

Differences between plots in the presence or absence of blue grass also showed statistically significant results when averaged over N rate and N source. Plots infested with bluegrass resulted in lower dry matter accumulation at both Feekes GS 9.1 and 11.4 and significantly lower yields. Although the influence of N rate and Source was not significant here the results did show that a substantial portion of yield could be recovered with addition of N where bluegrass was present and ammonium sulfate did show a trend to out preform urea at all rates.

Table 7. Total dry matter accumulation (2001) by winter wheat at Feekes GS 9.1 and 11.4 averaged over N-source and N-rate.

	Dry Matter Accumulation			
	Feekes 9.1		Feekes 11.4	
Bluegrass	**TDM**	**Straw**	**Spikes**	**TDM**
Treatment	------kg ha^{-1}------			
+ Bluegrass	3871	3242	4211	7453
- Bluegrass	4278	3815	5051	8866
† LSD(0.05)	364	290	352	676

† LSD(0.05) = least significant differences among bluegrass treatments within a column.

Table 8. Fertilizer N recovery in the soil at Feekes GS 10.1 and 11.4.

	Fertilizer N Recovery	
N-Rate	**Feekes GS 10.1**	**Feekes GS 11.4**
----kg N ha^{-1}----	**------% of applied------**	
0	0	0
89	39	37
134	48	36
179	50	32
† LSD(0.05)	5.4	3.8

† LSD(0.05) = least significant differences among N rates in a column.

Literature Cited

Baethgen, W.E., and M.M. Alley. 1989. Optimizing soil and fertilizer nitrogen use by intensively managed winter wheat. II. Critical levels and optimum rates of nitrogen fertilizer. Agron. J. 81:120-125.

Bashir, R., R J. Norman, R.K. Bacon, and B.R. Wells. 1997. Accumulation and redistribution of fertilizer nitrogen-15 in soft red winter wheat. Soil Sci. Soc. Am. J. 61:1407-1412.

Bouwmeester, R.J.B., P.L.G. Vlek, and J.M. Stumpe. 1985. Effect of environmental factors on ammonia volatilization from a urea-fertilized soil. Soil Sci. Soc. Am. J. 49:376-381.

Bremmner, J.M , and C.S. Mulvaney. 1982. Nitrogen-Total. P. 595-624. In A.L. Page et al. (ed.) Methods of Soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Brady, N.C., and R.R. Weil. 1996. The Nature and Properties of Soils. P. 328-359. Prentice Hall. Upper Saddle River, NJ.

Eivazi, F. 1998. Urease activity in soils subjected to flooding and its effect on nitrogen uptake by corn and wheat. J. Plant Nutr. 21:699-705.

Katyal, J.C., and M.F. carter. 1989. Effect of airflow rate leaching, and presubmergence on ammonia volatilization and apparent denitrification loss of nitrogen form a submerged soil. Soil Sci. 147:116-125.

Keeney, D.R , and D.W. Nelson. 1982. Nitrogen-Inorganic Forms. P. 625-642. In A.L. Page et al (ed.) Methods of Soil Analysis. Part 2 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Mulvaney, R.L. 1986. Comparison of procedures for reducing cross-contamination during steam distillations in nitrogen-15 tracer research. Soil Sci. Soc. Am. J. 50:92-96.

Myrold, D.D. 1998. Transformations of Nitrogen. P. 259-294. In Principles and Applications of Soil Microbiology. Prentice Hall Inc. Upper Saddle River, NJ.

Olson, R.V. 1982. Immobilization, nitrification, and losses of fall-applied, labeled ammonium-nitrogen during growth of winter wheat. Agron. J 74:991-995.

Sharpe, R.R., L.A. Harper, J.E. Giddens, and G.W. Langdale. Nitrogen use efficiency and nitrogen budget for conservation tilled wheat. Soil Sci. Soc. Am. J. 52:1394-1398.

Tisdale, S.L., W.L. Nelson. And J.D. Beaton. 1985. Soil Fertility and Fertilizers. 4th (ed.) Macmillan Publishing Co. New York. P. 112-188

Vlek, P.L.G., and E.T. Craswell. 1979. Effect of nitrogen source and management on ammonia volatilization losses form flooded rice soil systems. Soil Sci. Soc. Am. J. 43:352-358.

Wilson, C.E.Jr., R.J. Norman, and B.R. Wells. 1989. Seasonal uptake patterns of fertilizer nitrogen applied in split applications to rice. Soil Sci. Soc. Am. J. 53:1884-1887