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ABSTRACT

Rice production in Arkansas is one of the top three crop commodities in terms of cash receipts. Researchers and farmers report that nitrogen (N) needs to be managed according to a variety of factors with two important ones being soil and fertilizer type. The objectives of this experiment were to determine: 1) the degree to which floodwater-incorporated N applied as urea or as ammonium sulfate infiltrates intact cores (7.2-cm dia., 10-cm depth) containing DeWitt silt-loam soil, and 2) the distribution of N during 12 h of ponding. Inorganic-N concentrations were analyzed at 2-cm depth intervals in cores following removal of the flood. Nitrogen from applied fertilizer was recovered as ammonium. Ammonium sulfate-N remained in the top 4 cm of soil with concentrations of 375 μg N g^{-1} in the surface 2 cm and 300 μg N g^{-1} at the 2 - 4 cm depth after 12 hr of ponding. At all depth intervals below 4 cm, ammonium sulfate-N remained below 30 μg N g^{-1}. In contrast, after 12 h of ponding, N in soil receiving urea was 105 μg N g^{-1} in the top 2 cm and 173 μg N g^{-1} at 2-4 cm. At 4-6, 6-8, and 8-10 cm, N was 109, 108, and 35 μg N g^{-1}, respectively, after 12 h of ponding. These results demonstrate immediate and deeper movement of ammonium into silt loam soil receiving urea as compared to ammonium sulfate, demonstrating how the form of N in fertilizer affects its movement into the soil profile.

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MEET THE STUDENT-AUTHOR

Lindsay M. Copenhaver

I graduated from Conway High School in 2004 and enrolled in the University of Arkansas in fall 2004 as an environmental, soil, and water sciences major with minors in chemistry and global agriculture, food, and life sciences. I was awarded the Honors college Academy Scholarship as well as the Agriculture Beginning Scholarship, Charles A. Stutte Memorial Scholarship, R.P. and Mildred Bartholomew Scholarship, Johnnie N. Jenkins Scholarship, and Delta Classic Scholarship from the Dale Bumpers College of Agricultural, Food and Life Sciences and from the Department of Crop, Soil and Environmental Sciences. I am a member of the Environmental, Soil and Water Sciences Club.

I began working in the Soil Biology and Microbial Ecology lab with Dr. Savin during the fall of my freshman year, where I was introduced to and began working on y honors research thesis concerning nitrogen movement in Arkansas rice soils. I applied and received the Student Undergraduate Research Fellowship (SURF) and the Carroll Walls Research Stipend for the 2006 academic year. I attended the American Society of Agronomy meeting in Salt Lake City in fall of 2005 where I placed second in the Undergraduate Oral Research Symposium. I competed in the 2006 Gamma Sigma Delta undergraduate research competition and placed second. I plan on continuing my graduate studies after I receive my environmental, soil, and water sciences degree.

INTRODUCTION

Arkansas has been the nation's leading rice-producing state since 1973, ranking first in acres planted and producing about 40 to 45% of the U.S. rice crop annually (Slaton, 2001). Approximately 55, 35, and 9% of the rice grown in Arkansas is produced on silt-loam, clay, and sandy-loam soils, respectively. Field preparation has the primary objective of removing winter vegetation and reducing the chance of seedling drift, so most Arkansas rice production is a delayed-flood, direct dry-seeded culture, with flooding of fields beginning at the end of May and early June.

Nitrogen (N) fertilizer is one of the most important investments, monetarily and environmentally, in a successful rice crop (Wilson et al., 2005). Nitrogen accounts for approximately 67% of the fertilizer (N + P + K) applied to rice (Vlek and Byrnes, 1986). While the amount of N required depends on rice culture, soil conditions, cultural practices, crop rotations, and other factors (Wilson et al., 2005), the goal of any fertilization program is to apply the optimal rate that will result in maximal yields.

Due to the complicated transformations N can undergo and the potential for inefficient N use, N is difficult to manage in flooded soil systems (Reddy and Patrick, 1984). Recovery by rice can be as low as 20 to 40%, if managed poorly, leading to extensive N losses (DeDatta et al., 1988). Because nitrate serves as an electron acceptor during denitrification, the use of nitrates for fertilization is avoided. Urea ((NH2)2CO) is an ammonium-forming N source that is widely available, relatively inexpensive, and has a large percentage (46%) of N. More than 90% of the total fertilizer-N is applied as urea instead of other forms (Vlek and Byrnes, 1986). Ammonium sulfate is another reduced-N source but is generally more expensive and has lower N content (21%), which also increases application costs (Wilson et al., 2005).

The movement of N from urea and ammonium sulfate on a silt-loam soil was analyzed in a laboratory study with a simulated field "flood." The objective was to measure the immediate movement of N into the surface soil and compare how the different fertilizer N forms affected the depth to which N moved within 12 h of application and water ponding. It was hypothesized that N from urea would move farther down into the soil than N from ammonium sulfate.

MATERIALS AND METHODS

Soil cores.

Fifty-four intact soil cores (7.2 cm-dia., 10 cm-length) were collected from a 1.1 x 2.3 m plot at the University of Arkansas Rice Research and Extension Center, Stuttgart. Cores were kept intact inside plastic sleeves, placed on ice for transportation, and stored at 4°C. At the same time, five samples were taken for bulk density and 10 samples were taken for chemical composition (Mehlich III, total C & N, pH, N, OM, EC, P & K). Soil chemical composition was determined at the Soil Test Laboratory at the University of Arkansas, Fayetteville.

Infiltration and movement of N in top 10 cm of soil.

Nitrogen (90 mg N for each fertilizer) was applied to the center of cores (202.3 mg urea or 444.5 mg ammonium sulfate). Just enough water was added to dissolve the fertilizer, and then a flood was applied and maintained using Mariotte bottles (Fig. 1). The principle of the Mariotte bottle is that the pressure inside the bottle at the bottom of the bubble tube is at atmospheric pressure, which then maintains the water surface in the soil core at the same height as the end of the bubble tube (Bouwer, 1986) (Fig. 1).

Cores (four replications for a total of 48 cores) were leached at time intervals of 0.5, 1, 2, 4, 8, or 12 h for each fertilizer. When the allotted time elapsed, the floodwater and leachate were collected; volumes were measured, and frozen. Each core itself was capped and immediately placed in a -80°C freezer. Background N concentrations before (three replications) and after 12 h of flooding (three replications) were determined in cores not receiving N fertilizer.

Analysis.

The frozen cores were cut at 2-cm depth intervals with a band saw. Each thawed section was homogenized with a glass stirring rod. Moisture content was determined gravimetrically after drying 5 g of wet soil at 105°C for 24 h using the following equation:

$$\theta g = (W - D)/D \quad x \quad 100 \qquad (1)$$

where θg = gravimetric moisture, W = wet soil (g), and D = dry soil (g). Inorganic N was measured in 2M KCl solutions (1:10 soil:extract) after shaking for 1 h and filtering through a Whatman #42 filter. Filtrate was stored at 4°C, or frozen if analysis could not be conducted within a month of extraction, before colorimetric analysis of nitrate and ammonium (Mulvaney, 1996) on a nutrient autoanalyzer (Skalar Instruments, Norcross, Ga.). In the analysis procedure, NO_{3^-} extracted from soil with 2M KCl is reduced to NO_{2^-} by passage through a column of copperized cadmium, and the NO_{2^-} formed is determined by a modified Griess-Ilosvay method (Mulvaney, 1996). NH_4^+ extracted from soil with 2M KCl is determined by measuring the intensity of the emerald green color that forms upon treatment of an aliquot of the extract with salicylate and hypochlorite at high pH. A catalyst (sodium nitroprusside) increases the rate and intensity of color development, and a chelating agent (EDTA) prevents the precipitation of divalent and trivalent cations as hydroxides (Mulvaney, 1996).

Mean N concentrations and standard deviations were calculated for each depth and time interval. Concentrations were analyzed and compared across fertilizer type and over time using analysis of variance. Background soil-N concentrations were subtracted from the measured 12-h concentrations to obtain fertilizer-N concentrations.

RESULTS AND DISCUSSION

The soil chemical properties of the DeWitt silt loam (fine, smectitic, thermic, Typic Albaqualf) are summarized in Table 1. According to Brady and Weil (2002), the range for an average silt-loam soil bulk density is 0.9 – 1.5 g/cm^3, with a typical medium-textured soil having a bulk density of 1.25 g/cm^3. The DeWitt silt-loam bulk density is well within the reported range with an average bulk density of 1.38 g/cm^3. Carbon and pH values also fell within normal ranges of 0.9-3.3% for carbon and 5-7 for pH (Brady and Weil, 2002).

Neither fertilizer contained N in nitrate form and because of the short time intervals used in this study, nitrification was not expected to occur. Fertilizer was expected to be recovered as NH_4^+-N. In fact, after subtracting out background nitrate levels after 12 h of ponding, almost all inorganic N recovered was ammonium (data not shown).

Floodwater incorporated NH_4^+-N into soil to varying degrees within the 12-h ponding time utilized in this study. The concentrations of NH_4^+-N at the 0-2 cm depth ranged from 523 µg N g^{-1} soil measured after 0.5 h to 375 µg N g^{-1} soil after 12 hours. Nitrogen at the 2-4 cm depth after 0.5 h was 154 µg N g^{-1} soil and after 12 h was 300 µg N g^{-1} soil. These results represent an accumulation in the upper 4 cm. There was a sharp, visible downward trend over time in 0-2 cm depth, accompanied by a similarly apparent increase in the 2-4 cm depth (Fig.

2). Below 2-4 cm, accumulation was slow, and inconsistent with concentrations ranging from a background 9 µg N g^{-1} to 29 µg N g^{-1} soil after 12 h. There was no significant downward movement below 4 cm when compared to the upper 4 cm (Fig. 2). These results were expected because the positive charge of ammonium ($NH4+$) associates with negative charges on soil-particle surfaces.

In contrast to ammonium sulfate applied-N, there was deeper movement of NH_4^+-N from surface-applied urea (Fig. 3). In order to measure increases in NH_4^+ with urea applications, NH_4^+ must be released during breakdown of composition of urea, leading to the expectation that urea will be able to move farther down into the soil. Concentrations of NH_4^+-N were 130 µg N g^{-1} soil after 0.5 h and 105 µg N g^{-1} soil after 12 hours at 0-2 cm (Fig. 4). Nitrogen was approximately 175 µg N g^{-1} soil at the 2-4 cm depth after a 0.5 h and remained at 175 µg N g^{-1} after12 h of ponding. In contrast, NH_4^+ concentrations at the 4-8 cm depths were higher than those measured in soil receiving ammonium sulfate (Figs. 2 and 3). Ammonium concentrations at the 4-8 cm depth also increased during 12 h of flooding. At the 4-6 and 6-8 cm depths, 75 and 39 µg N g^{-1} soil, respectively, were measured after 0.5 h of ponding and concentrations reached approximately 109 µg N g^{-1} soil at both depths after 12 h (Fig. 3). Although concentrations of urea were not as high in the top 4 cm as ammonium sulfate, concentrations below 4 cm increased over time (Fig 3).

While N from ammonium sulfate stayed in the surface 4 cm of soil, N from urea infiltrated farther and was accumulating at depths below 4 cm during 12 h of ponding. These results have significance because if urea breaks down to release ammonium before a flood is established, fertilizer N will behave more like ammonium sulfate and N will not infiltrate as far. Any ammonium that remains at the surface and under aerobic conditions can undergo nitrification. Nitrate can leach with downward water movement and move into the anaerobic zone. In the anaerobic zone, nitrate can undergo denitrification. Some cultural practices take 5 d to establish a flood. These results suggest that management practices that prevent the breakdown of urea and the subsequent accumulation of NH_4^+-N near the soil surface need further investigation.

ACKNOWLEDGMENTS

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Table 1. Mean soil properties (± standard deviation) of a DeWitt silt-loam soil (fine, smectitic, thermic, Typic Albaqualf) collected from the University of Arkansas Rice Research and Extension Center, Stuttgart (n=5 for bulk density, n=10 for all other properties).

pH	EC[z]	P	K	C	N	OM	Bulk Density
	(umhos/cm)	(mg/kg)	(mg/kg)	(%)	(%)	(%)	(g/cm^3)
6.37	164.80	10.43	108.34	0.95	0.09	2.37	1.38
(0.03)	(7.16)	(0.39)	(3.25)	(0.02)	(0.00)	(0.14)	(0.02)

[z]EC is electrical conductivity and OM is organic matter.

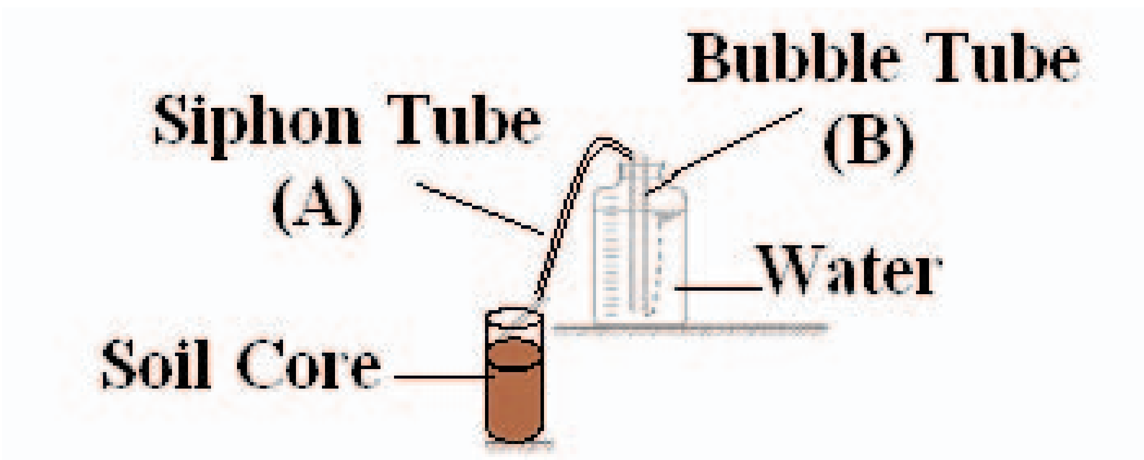

Fig. 1. Mariotte Bottle. Two tubes are inserted through the stopper. One tube (A) is for siphoning the water to the soil core and the other tube (B) allows air into the bottle. The bottom of this "bubble" tube is set at the level at which the water surface in the soil core is to be maintained (Bouwer, 1986).

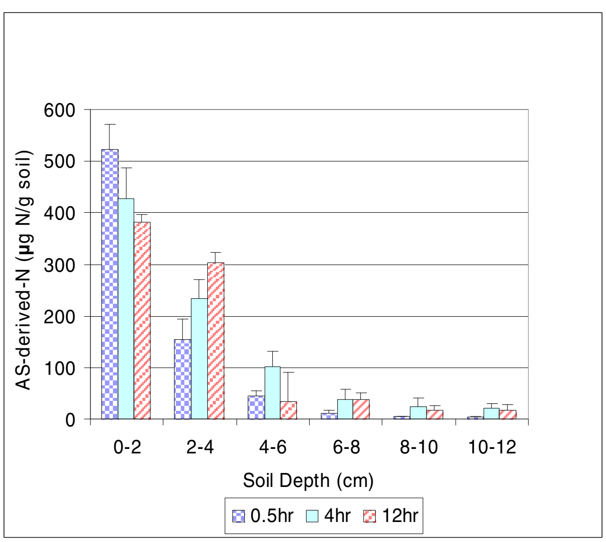

Fig. 2. Mean NH4+-N concentrations (± standard deviation) from ammonium sulfate (AS) recovered after time intervals of 0.5, 4 or 12 h at 2-cm depth intervals in soil cores containing DeWitt silt loam.

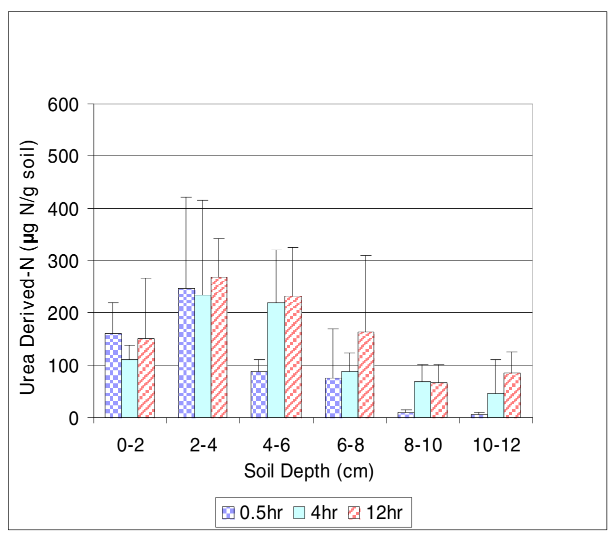

Fig. 3. Mean NH4+-N concentrations (± standard deviation) from urea recovered after time intervals of 0.5, 4 or 12 h at 2-cm depth intervals in soil cores containing DeWitt silt loam.