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Rice Grain Yield As Influenced By N Source, N Rate, and N Application Time

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INTRODUCTION

Nitrogen (N) fertilizer must be applied in the proper amounts and times to produce maximum agronomic rice (*Oryza sativa* L.) yield. Currently, the most efficient method of N fertilization for rice grown in the direct-seeded, delayed-flood production system is to apply an ammonium or ammonium-forming N source (e.g., urea) to a dry soil surface near the 5-leaf stage of rice growth and incorporate the N quickly by establishing a flood that will be maintained for the duration of the growing season. Norman et al. (2003) reported that rice recovery of properly managed preflood urea-N was 60 to 75% of the total applied N. A second application of N fertilizer (~45 lbs N acre^{-1} as urea) is generally applied into the floodwater near the panicle differentiation (PD) stage 4 to 5 wk after the preflood N application. Following the recommended N fertilization guidelines allows for high yields, minimizes environmental N losses, and represents the most cost-efficient means for sufficient N fertilization of flood-irrigated rice.

Urea and ammonium sulfate are the N fertilizers recommended for preflood fertilization of rice in Arkansas (Slaton, 2001), however urea is the most commonly used N fertilizer for rice due to its high N analysis and relatively low cost. One major disadvantage of surface application of urea-N is the potential for substantial N loss via NH_3 volatilization, which is one of the two most prevalent N loss mechanisms in the dry-seeded, delayed-flood production system, with the other being denitrification of soil- or fertilizer-N that has undergone nitrification.

Griggs et al. (2007) showed NH_3 volatilization losses ranged from 20 to 30% of the total urea-N applied to a silt loam 14 d before flooding. Ammonia volatilization losses from $(NH_4)_2SO_4$ were lower (<5%) compared with urea. The data of Griggs et al. (2007) shows that a significant proportion of N can be lost via NH_3 volatilization even when proper N and water management practices are followed on silt loam soils. Our research objectives were to: i) measure the ammonia volatilization of urea with and without Agrotain-LC or Weyerhaeuser urease inhibitors; ii) determine the influence of addition of urease inhibitors to urea when applied at varying N rates at multiple application times on aboveground N uptake at the late boot/early heading stage of rice growth and development; and iii) describe the differences in rice grain yield as affected by N rate, and application timing of two urease inhibitors as compared to urea-N application. The ultimate goals of these experiments were to determine if Agrotain-LC or Weyerhaeuser-Arborite treated urea would increase rice grain yield by effectively limiting NH_3 volatilization compared to untreated urea when applied several days in advance of the permanent flood.

MATERIALS AND METHODS

Description of Experimental Site

Research was established in 2010 to evaluate the influence of urease inhibitors and time of N application on rice grain yield and N uptake. The experiment was established at the Rice

Research and Extension Center on a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualfs). Soybean [*Glycine max* (L.) Merr.] was the previous crop grown in rotation.

Eight composite soil samples (two per bay) were collected from the 0- to 4-inch depth at each site before seeding rice. Each composite sample consisted of eight, 1-inch diameter cores. Soil samples were oven-dried, crushed to pass through a 2-mm sieve, extracted with Mehlich-3 (Mehlich, 1984), and extracts were analyzed using inductively coupled plasma atomic emission spectroscopy. Soil water pH was determined in a 1:2 soil weight:water volume ratio using a glass electrode. Total soil N and C were determined by combustion (LECO CN2000, St. Joseph, MI; Nelson and Sommers, 1996). The mean values of selected soil chemical properties are listed in Table 1.

Treatments

Individual plots, measuring 6.5-ft wide × 16-ft long, were flagged to establish plot boundaries. Phosphorus (36 lb P_2O_5/acre as triple superphosphate) and K (72 lbs K_2O/acre as muriate of potash) fertilizers were broadcast to all plots. Zinc (10 lb Zn/acre as $ZnSO_4$) was also applied to the research area.

The long-grain rice cultivars 'Wells' was drill-seeded into conventionally tilled seedbeds at 80 lb seed/acre. Each plot contained nine rows of rice spaced 7 inches apart and was surrounded by a 1.5-ft wide alley that contained no rice. Urea, Agrotain-LC treated urea, and Weyerhaeuser-Arborite treated urea were applied at rates equivalent to 60 and 120 lb N/acre. An unfertilized control was also included in the study. Each N source was applied at three timings, 10, 5, and 1 d before flooding (DBF) onto a dry soil surface. Following the 1 d N application, a 4-inch deep permanent flood was established and maintained until rice reached physiological maturity. The dates of several agronomic events are listed in Table 2. In general, rice management closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, pest management, and irrigation management (Slaton et al., 2001).

Measurements

Aboveground plant samples were collected near the late-boot to early-heading (HDG) stage to evaluate N-fertilizer uptake among the three N-fertilizer sources. The HDG stage represents maximal N accumulation by rice during the growing season (Guindo et al., 1994). Plant samples were taken from a 3-ft section in the first inside row of each plot. Samples were dried at 60ºC in a forced-draft oven, weighed, and ground to pass through a 1-mm sieve. A 0.20- to 0.30-g subsample was weighed into a tared Elementar macroN crucible (Elementar, Mount Laurel, NJ) and total N was determined by combustion (Elementar Vario Max CN, Mount Laurel, NJ; Campbell, 1992).

Aboveground N content was calculated by multiplying the whole-plant N concentration with total aboveground dry matter accumulation. Grain yield was determined at physiological maturity by harvesting 65-ft^2 from the middle of each plot with a small plot combine. Grain weights and moisture contents were recorded and grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

Statistical Analysis

The experiment was a randomized complete block with treatments defined by 3 N sources applied at 2 N rates with 3 N application times plus an unfertilized control (0 lb N/acre). Each treatment was replicated four times. Nitrogen uptake and rice grain yield data were analyzed as a 3-factor factorial. Nitrogen uptake and rice grain yield means were separated using Fishers protected least significant difference (LSD) at the 0.05 and 0.10 significance level when appropriate. All statistical analysis was conduct with the GLM procedure in SAS ver. 9.1 (SAS Institute, Cary, NC).

Laboratory Incubation Study for Ammonia Volatilization

The three N fertilizer sources, urea, Agrotain treated urea and Arborite treated urea, were applied to a DeWitt silt loam soil (20% volumetric water content) which was the same soil used for the field study. The soil (50g) was placed in a glass diffusion chamber to a depth of 2.5 cm and the N fertilizer sources are applied at a rate of 202 kg N/ha (180 lb N/acre) to the surface of the soil without any incorporation. A boric acid trap was suspended within the chamber to catch any ammonia volatilized from the soil. Ammonia volatilization was measured over a 21 day period at 25^{o}C. Sampling times were at 4, 7, 11, 15, and 21 days after N fertilizer application. The study was arranged in a randomized complete block design with four replications. Statistical analyses were conducted on the ammonia volatilization data with SAS and mean separations based upon protected LSD where appropriate.

RESULTS AND DISCUSSION

Rice grain yield

Rainfall during the 10 d prior to flooding when the urea fertilizer was either being applied or had been applied was minimal and not sufficient to incorporate the urea fertilizer into the soil (Table 3). In addition, the temperatures during the day were in the high 80s and low 90s^{0}F. Thus, the environment was conducive for ammonia volatilization of urea and perfect for conducting a study to evaluate a urease inhibitor.

There was no three-way nor any two-way interactions between N source, N rate, and/or N application timing on rice grain yield at the $P<0.05$ or 0.10 levels (Table 4). However, there were significant main effects of N rate (P<0.0001), N application timing (P<0.0001), and N source (P=0.0003) on rice grain yield.

Rice grain yield was significantly affected by N rate when averaged across N sources and N application times (Table 5). Thus indicating there was a positive response to N fertilizer and the site was appropriate for a N response study. Our new nitrogen soil test for rice (i.e., N-ST*R) indicated a rice variety like 'Wells' should require 85 lb N/acre to maximize yield on this soil (Roberts et al., 2010). Rice grain yield increased as the N rate was incrementally increased from 0 to 60 lb N/acre and finally to 120 lb N/acre.

Application time of the N fertilizer in reference to establishment of the permanent flood significantly affected rice grain yield when averaged across N rate and N source (Table 6). As the time between N application and flooding was increased from 1 to 5 d there was not a significant decrease in rice grain yield at the α=0.05 nor at the α=0.10 level. However, there was a significant decrease in rice grain yield when the time between N application and flooding was increased from 1 to 10 d and 5 to 10 d at both the α=0.05 and 0.10 level. Consequently, the decrease in yield as the time between N application and flooding was increased indicates there was ammonia volatilization loss over the 10 d prior to flooding and the study was suitable for evaluating a urease inhibitor.

Averaged across N rates and N application times rice grain yield was significantly affected by N source at α=0.05 and 0.10 levels (Table 7). All N sources resulted in a grain yield significantly higher than the control. Arborite treated urea and Agrotain treated urea resulted in similar mean grain yields which were significantly higher than the rice grain yield obtained with untreated urea. Thus, the grain yield results indicate Arborite was as effective as Agrotain in minimizing ammonia volatilization loss and maintaining grain yield as the time between N fertilizer application and flooding was delayed from 1 to 10 d.

Although there was no three-way interaction between N source, N rate, and N application timing on rice grain yield at the $P<0.05$ or 0.10 levels, Table 8 was included with the interaction for your perusal.

Ammonia Volatilization Laboratory Study

Shown in Table 9 are the cumulative ammonia volatilization results from the laboratory-incubation study for each of the three N sources measured at 3, 4, 11, 15, and 21 days after N fertilizer application. Urea (check) lost the most N via ammonia volatilization of the products tested with 2.5% by day 4, 15.3% by day 7, 28.6% by day 11, 36.4% by day 15, and 40.6% by day 21. Both Agrotain and Arborite significantly inhibited and slowed ammonia volatilization from urea over the 21 day incubation. Agrotain treated urea and Arborite treated urea lost little N to ammonia volatilization over the 21 day incubation. Agrotain and Arborite treated urea lost similar small amounts of N via ammonia volatilization over the first 15 days of incubation, but between day 15 and day 21 the Arborite treated urea lost significantly more than Agrotain treated urea. By day 11, Agrotain and Arborite treated urea lost <0.3% of the urea via ammonia volatilization and by day 15 only lost 0.5% and 1.4%, respectively. By day 21, Agrotain and Arborite were losing their effectiveness as indicated by the cumulative ammonia volatilization of Agrotain treated urea increasing from 0.52% on day 15 to 2.7% by day 21 and Arborite treated urea increasing from 1.4% on day 15 to 6.4% by day 21. Although the laboratory incubation method does not exactly mimic ammonia volatilization in the field, it does allow us to compare products ammonia inhibition relative to each other. These ammonia volatilization results over the first 15 days of the laboratory incubation reflect the results we collected in the field when we delayed the flood for up to 10 days; that is, over a 10 day period Arborite and Agrotain inhibit ammonia volatilization of urea similarly.

Total Aboveground Nitrogen Uptake

There was no three-way nor any two-way interactions between N source, N rate, and/or N application timing on rice grain yield at the $P<0.05$ or 0.10 levels (Table 10). However, there were significant main effects of N rate ($P<0.0001$), N application timing ($P=0.0003$), and N source ($P=0.0132$) on total N uptake. The total N uptake results mimic very closely the rice grain yield results.

Total N uptake was significantly affected by N rate when averaged across N sources and N application times (Table 11). This indicates there was a positive response to N fertilizer and the site was appropriate for a N response study. As stated earlier, our new nitrogen soil test for rice (i.e., N-ST*R) indicated a rice variety like 'Wells' should require 85 lb N/acre to maximize yield on this soil (Roberts et al., 2010). Total N uptake increased as the N rate was incrementally increased from 0 to 60 lb N/acre and finally to 120 lb N/acre.

Application time of the N fertilizer in reference to establishment of the permanent flood significantly affected total N uptake when averaged across N rate and N source (Table 12). As the time between N application and flooding was increased from 1 to 5 d there was not a significant decrease in total N uptake at the $\alpha=0.05$ nor at the $\alpha=0.10$ level. However, there was a significant decrease in total N uptake when the time between N application and flooding was increased from 1 to 10 d and 5 to 10 d at both the $\alpha=0.05$ and 0.10 level. Consequently, the decrease in total N uptake as the time between N application and flooding was increased indicates there was ammonia volatilization loss over the 10 d prior to flooding and the study was suitable for evaluating a urease inhibitor.

Total N uptake was significantly affected by N source at α=0.05 and 0.10 levels when averaged across N rates and N application times (Table 13). All N sources resulted in a total N uptake significantly higher than the control. Arborite treated urea and Agrotain treated urea resulted in similar mean total N uptakes which were significantly higher than the total N uptake obtained with untreated urea. Thus, the total N uptake results mimic the grain yield results as well as the ammonia volatilization results and indicate Arborite was as effective as Agrotain in minimizing ammonia volatilization loss and maximizing total N uptake as the time between N fertilizer application and flooding was delayed from 1 to 10 d.

Although there was no three-way interaction between N source, N rate, and N application timing on total N uptake at the $P<0.05$ or 0.10 levels, Table 14 was included with the interaction for your perusal.

SUMMARY

Results of the 2010 study comparing Arborite treated urea with Agrotain treated urea and untreated urea indicated that the site chosen for the study required N fertilizer to maximize rice yield and that there was significant ammonia volatilization loss of untreated urea. Thus, the soil at the site was conducive for an N rate study and the soil and environmental conditions that prevailed over the 10 days prior to flooding were suitable for conducting an ammonia volatilization study and evaluating a urease inhibitor.

Arborite and Agrotain treated urea were effective urease inhibitors that significantly slowed and minimized the ammonia volatilization of urea. The two products appeared almost identical in their performance in the laboratory as well as the field. The inhibition of ammonia volatilization of urea by Arborite and Agrotain was substantial enough in the field over the 5 and 10 days prior to flooding to result in a significant increase in total N uptake and grain yield when compared to untreated urea. We need one more year of data with similar results before we can make a recommendation for Arborite's use in rice in Arkansas.

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Table 1. Selected soil chemical property means (*n* = 8) of research established at the Rice Research Extension Center (RREC) on a Dewitt silt loam in 2010.

Site	Soil pH	Mehlich-3 extractable nutrients							
		P	K	Ca	Mg	Na	S	Cu	Zn
	(1:2)	- - - - - - - - - - - - - - - - mg kg^{-1} - - - - - - - - - - - - - - - -							
East Bay	6.2	33	167	1086	192	58	9.3	1.1	6.4
West Bay	6.0	29	178	1043	184	54	8.5	1.3	6.2

Table 2. Pertinent agronomic information for the research study at the Rice Research and Extension Center during 2010.

Practices	**Dates and Rates**
Preplant Fertilizers	200 lb/A 0-18-36 + 30 lb/A $ZnSO_4$
Planting Date	6/16
Emergence Date	6/22
Herbicide Spray Dates and Procedures	5/28 = 0.5 pt/A Command + 0.5 lb/A Facet 7/8 = 24 oz/A RiceStar HT + 1 oz Permit + 1%COC 7/14 = 24 oz/A RiceStar HT + 1 oz Permit + 1%COC
Insecticide Spray Dates Procedures	7/28 = 3 oz/A Karate 8/6 = 3 oz/A Karate
Preflood N Dates	7/5 = 10 days 7/10 = 5 days 7/14 = 1 day
Flood Date	7/15
50% Heading Date	NA
Harvest Date	10/28

Table 3. Soil and air temperatures and rainfall events during the 10 days of nitrogen (N) fertilization prior to flood establishment at the Rice Research and Extension Center in 2010.

	Soil		Air		Rainfall
Date	**Max**	**Min**	**Max**	**Min**	**hundredths**
5-Jul-10	92	81	92	72	
6-Jul-10	93	81	94	74	
7-Jul-10	91	81	-----	-----	0.03
8-Jul-10	89	82	93	74	
9-Jul-10	93	80	94	76	
10-Jul-10	88	81	90	74	
11-Jul-10	90	80	91	75	trace
12-Jul-10	90	83	92	77	trace
13-Jul-10	90	81	95	71	0.26
14-Jul-10	89	81	89	72	0.08
15-Jul-10	92	82	96	77	

Table 4. Analysis of variance *p* values for rice grain yield as affected by nitrogen (N) source, N rate, N timing and their interactions for the study at the Rice Research and Extension Center in 2010.

Parameter	Value
R Square	0.81666
C.V.	5.286
p-value N source	0.0003
p-value N rate	<0.0001
p-value N timing	<0.0001
N source*N rate	0.7602
N source*N timing	0.2317
N source*N rate*N timing	0.5480

Table 5. Influence of Nitrogen (N) rate on rice grain yield at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Rate	Grain Yield
----- (lbs N/acre) -----	----- (bushels/acre) -----
60	128
120	141
Control	98
$LSD_{(\alpha=0.05)}$	6.3
$LSD_{(\alpha=0.10)}$	5.3

Table 6. Influence of Nitrogen (N) application timing on rice grain yield at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Timing	Grain Yield
----- (dpf^z) -----	----- (bushels/acre) -----
1	139
5	135
10	128
$LSD_{(\alpha=0.05)}$	6.1
$LSD_{(\alpha=0.10)}$	5.1

dpf^z=number of days prior to establishment of permanent flood

Table 7. Influence of Nitrogen (N) source on rice grain yield at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Source	Grain Yield
	----- (bushels/acre)-----
Urea	129
Arborite	136
Agrotain	138
Control	98
$LSD_{(\alpha=0.05)}$	6.1
$LSD_{(\alpha=0.10)}$	5.1

Table 8. Influence of Nitrogen (N) source, rate, and application timing on rice grain yield at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Source	Grain Yield					
	60 lbs N/A			120 lbs N/A		
	1dpf[z]	5dpf	10dpf	1dpf	5dpf	10dpf
	(bushels/acre)					
Urea	130	120	116	146	138	126
Arborite	133	132	123	145	145	138
Agrotain	136	136	124	145	142	143
Control	98					
$LSD_{(\alpha=0.05)}$	n.s.					
$LSD_{(\alpha=0.10)}$	n.s.					

dpf[z]=number of days prior to establishment of permanent flood.

Table 9. Ammonia volatilization of urea based fertilizers during the 21 day incubation.

	Cumulative Ammonia Volatilization					
	Day 0	Day 4	Day 7	Day 11	Day15	Day 21
	(% of N applied)					
Urea (check)	0	2.5a	15.3a	28.6b	36.4b	40.6a
Agrotain LC	0	0.003b	0.05b	0.26b	0.5c	2.7c
Arborite	0	0.004b	0.02b	0.21b	1.4c	6.4b

Means within a column connected by the same letter are not significantly different at p<0.01.

Table 10. Analysis of variance *p* values for total N uptake as affected by nitrogen (N) source, N rate, N timing and their interactions for the study at the Rice Research and Extension Center in 2010.

Parameter	Value
R Square	0.70430
C.V.	14.914
p-value rep	0.5211
p-value N source	0.0132
p-value N rate	<0.0001
p-value N timing	0.0003
N source*N rate	0.7435
N source*N timing	0.7464
N rate*N timing	0.3420
N source*N rate*N timing	0.9475

Table 11. Influence of Nitrogen (N) rate on total N uptake of heading rice at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Rate	Total N Uptake
----- (lbs N/acre) -----	----- (lb N/acre)-----
60	124
120	166
Control	91
$LSD_{(\alpha=0.05)}$	14.2
$LSD_{(\alpha=0.10)}$	12.4

Table 12. Influence of Nitrogen (N) application timing on total N uptake of heading rice at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Timing	Total N Uptake
----- (dpf^z) -----	----- (lb N/acre)-----
1	157
5	147
10	131
$LSD_{(\alpha=0.05)}$	13.8
$LSD_{(\alpha=0.10)}$	11.3

dpf^z=number of days prior to establishment of permanent flood.

Table 13. Influence of Nitrogen (N) source on total N uptake of heading rice at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Source	Total N Uptake
	----- (lb N/acre)-----
Urea	135
Arborite	150
Agrotain	149
Control	91
$LSD_{(\alpha=0.05)}$	13.8
$LSD_{(\alpha=0.10)}$	11.3

Table 14. Influence of Nitrogen (N) source, rate, and application timing on total N uptake of heading rice at the Rice Research and Extension Center, Stuttgart, Arkansas, during 2010.

N Source	Total N Uptake					
	-------------- 60 lbs N/A --------------			-------------120 lbs N/A -------------		
	1dpf[z]	5dpf	10dpf	1dpf	5dpf	10dpf
	--- (lb N/acre) ---					
Urea	128	118	103	179	150	130
Arborite	135	127	120	183	181	156
Agrotain	134	129	122	181	175	154
Control	91					
$LSD_{(\alpha=0.05)}$	n.s.					
$LSD_{(\alpha=0.10)}$	n.s.					

dpf[z]=number of days prior to establishment of permanent flood