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YIELD AND YIELD COMPONENTS OF UPLAND RICE AS INFLUENCED BY NITROGEN SOURCES

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□ *Ammonium sulfate and urea are main sources of nitrogen (N) for annual crop production in developing countries. Two greenhouse experiments were conducted using ammonium sulfate and urea as N sources for upland rice grown on a Brazilian Oxisol. The N rates used were 0, 50, 100, 150, 3000, and 400 kg N kg^{-1} of soil. Yield and yield components were significantly increased in a quadratic fashion with increasing N rate. Ammonium sulfate X urea interaction was significant for grain yield, shoot dry matter yield, panicle number, plant height and root dry weight, indicating a different response magnitude of these plant parameters to two sources of N. Based on regression equation, maximum grain yield was achieved with the application of 380 mg N kg^{-1} by ammonium sulfate and 271 mg N kg^{-1} by urea. Grain yield and yield components were reduced at higher rates of urea (>300 mg kg N) but these plant parameters' responses to ammonium sulfate at higher rates was constant. In the intermediate N rate range (125 to 275 mg kg^{-1}), urea was slightly better compared to ammonium sulfate for grain yield. Grain yield was significantly related with plant height, shoot dry weight, panicle number, grain harvest index and root dry weight. Hence, improving these plant characteristics by using appropriate soil and plant management practices can improve upland rice yield.*

Keywords: *Oryza sativa* L., yield and yield components, shoot dry weight, root dry weight

INTRODUCTION

Nitrogen is one of the most yield limiting nutrient in crop production in all agroecological regions of the world (Fageria and Baligar, 2005). The main reasons of N deficiency in annual crops are its low recovery efficiency.

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In cereals N recovery efficiency at global level is reported to be less than 40% (Raun and Johnson, 1999; Raun et al., 2002). The low recovery efficiency of N is associated with its loss by leaching, disnitrification, volatilization and soil erosion (Fageria and Baligar, 2005). Nitrogen significantly improved yield of rice by improving yield components like panicle number, thousand grain weight, and reduced grain sterility (Fageria, 1992, 2007). In addition, N also improved grain harvest index, nitrogen harvest index and plant height which are positively associated with grain yield (Fageria, 2007).

For the efficient management of N in the cropping systems, adequate rate, appropriate source and timing of application during crop growth cycle play an important role (Fageria et al., 2006). Ammonium sulfate and urea are the main sources of N for annual crop production in developing countries. In developed countries, anhydrous ammonia is mainly used for annual crops. The application of anhydrous ammonia into the soil band requires special equipment, which is not readily available in the developing countries. In addition, the handling of liquid ammonia is also a problem for the farmers of developing countries. Hence, the main options for the farmers of developing countries are use of solid fertilizers like ammonium sulfate and urea. Data related to use of ammonium sulfate and urea in upland rice production are limited, especially for newly released cultivars of upland rice under Brazilian conditions. The objective of this research was to evaluate ammonium sulfate and urea in upland rice production in cerrado soil of Brazil.

MATERIALS AND METHODS

Two greenhouse experiments were conducted at the National Rice and Bean Research Center of EMBRAPA to evaluate ammonium sulfate and urea as sources of N in upland rice production under greenhouse conditions. The N rate applied was 0, 50, 100, 150, 300, and 400 mg kg^{-1} of soil. The soil used in the two experiments was an Oxisol having following chemical and physical characteristics before the application of N treatments: pH in water was 6.1, calcium (Ca) 1.9 $cmol_c$ kg^{-1}, magnesium (Mg) 1.4 $cmol_c$ kg^{-1}, aluminum (Al) 0.0 $cmol_c$ kg^{-1}, phosphorus (P) 1.3 mg kg^{-1}, potassium (K) 53 mg kg^{-1}, copper (Cu) 1.7 mg kg^{-1}, zinc (Zn) 1.7 mg kg^{-1}, iron (Fe) 77 mg kg^{-1}, manganese (Mn) 12 mg kg^{-1} and organic matter content 20 g kg^{-1}. The textural analysis was clay content 658 g kg^{-1}, silt content 120 g kg^{-1} and sand content 222 g kg^{-1}. Soil analysis methods used are described in soil analysis manual of EMBRAPA (1997).

Experiments were conducted in plastic pots with 9 kg of soil in each pot. At the time of sowing, each pot received 200 mg P, 200 mg K, and 10 mg Zn kg^{-1} of soil. Each pot also received 10 g dolomitic lime four weeks before sowing. The liming material had 33% calcium oxide (CaO), 14% magnesium oxide (MgO) and 85% neutralizing power. The pots were subjected to wetting and drying cycles. Experimental design was a complete block with three replications. Cultivar shown was BRS Sertaneja and there were four plants in each pot. Pots were watered everyday to maintain soil moisture at about field capacity during growth cycle. Shoots and grains were separated at harvest and material was dried in an oven at 70°C to a constant weight. Grain harvest index was calculated by using the following formula:

$$\text{Grain harvest index} = (\text{Grain yield})/(\text{Grain} + \text{straw yield})$$

At the time of harvesting, roots from each pot were removed manually to determine maximum length and dry weight. Roots were washed in water including distilled water several times before drying to a constant weight. Data were analyzed by analysis of variance and regression analysis was performed. Appropriate regression model was selected on the basis of R^2.

RESULTS AND DISCUSSION

Grain Yield

Nitrogen source X N rate interactions for grain yield, shoot dry weight, number of panicles, plant height and root dry weight were significant, indicating variability between two N sources for grain yield, yield components and growth parameters of upland rice. Hence, values of these characteristics are presented at two N sources at different N rates (Figures 1–5). Grain yield increased significantly in a quadratic fashion, when N rate was increased in the range of 0 to 400 mg kg^{-1} of soil, using ammonium sulfate and urea sources of N (Figure 1). Based on regression equations, maximum grain yield was obtained with the application of 380 mg N kg^{-1} of soil with the ammonium sulfate. Similarly, maximum grain yield was obtained with the application of 271 mg N kg^{-1} of soil by urea. Fageria et al. (2006) reported that maximum grain yield of upland rice in a Brazilian Oxisol was obtained

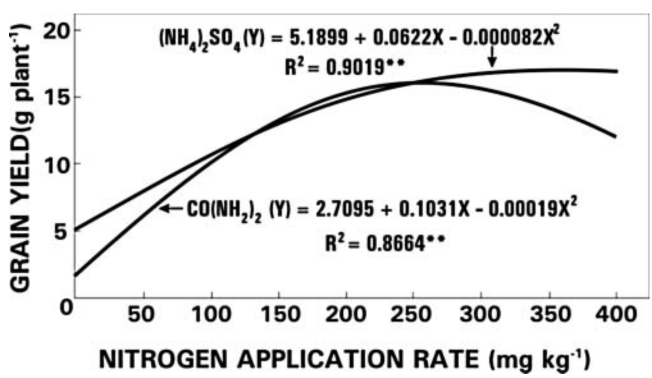

FIGURE 1 Relationship between nitrogen application rate by ammonium sulfate and urea and grain yield of upland rice.

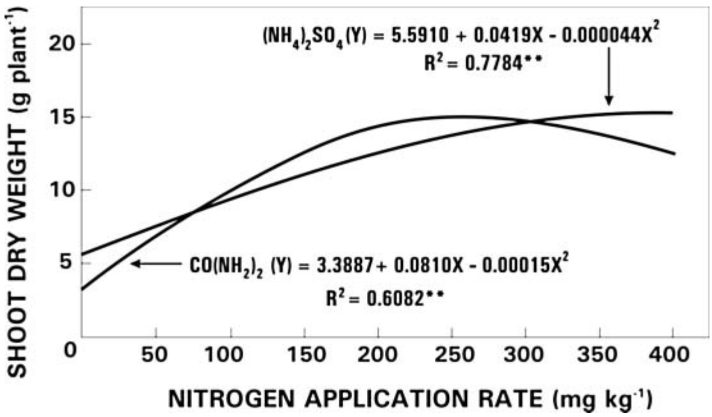

FIGURE 2 Relationship between nitrogen application rate by ammonium sulfate and urea and shoot dry weight of upland rice.

with the application of 400 mg N kg^{-1} of soil through ammonium sulfate. At the lower as well as at the higher N rates ammonium sulfate produced higher grain yield compared to urea. However, at the intermediate N rate (125 to 275 mg N kg^{-1}) urea was slightly superior in producing grain yield compared to ammonium sulfate. Across the six N rates, ammonium sulfate produced 12% higher grain yield compared to urea. The superiority of ammonium sulfate at higher N rates compared to urea maybe associated with higher acidity producing capacity of ammonium sulfate compared to urea. Rice is an acid-tolerant plant and its growth was linearly increased when Al saturation in the Brazilian Oxisol soil was increased from 0 to 30% (Fageria and Santos, 1998). Fageria (2000a) also reported that when soil pH of

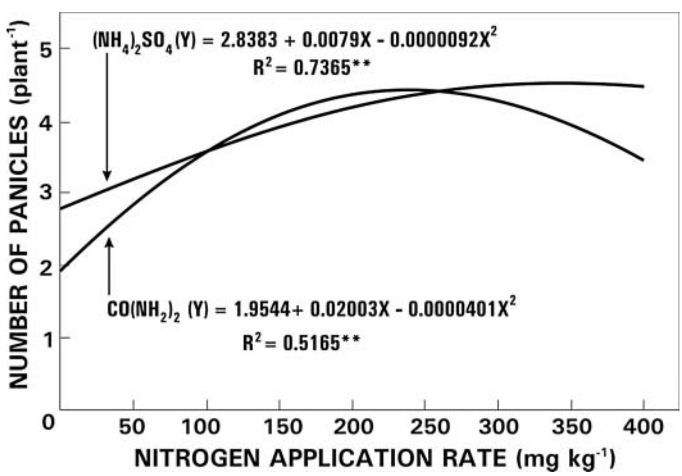

FIGURE 3 Relationship between nitrogen application rate by ammonium sulfate and urea and number of panicles of upland rice.

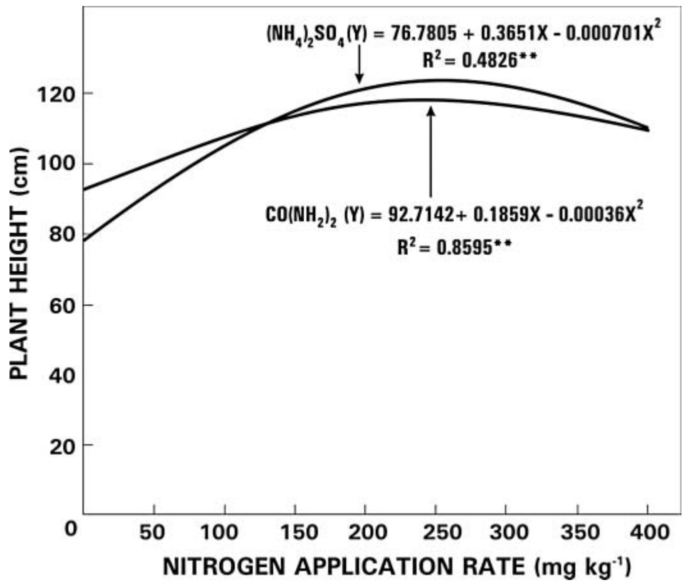

FIGURE 4 Relationship between nitrogen application rate by ammonium sulfate and urea and plant height of upland rice.

Brazilian Oxisol was raised from 4.6 to 6.8, upland rice plants showed iron deficiency at higher pH level (pH 5.7 in water) and yield was reduced. Uptake of Cu, M, Fe and Zn were reduced at higher pH (>5.7) (Fageria et al., 2002). Fageria (2009) also reported that rice plant growth was better at 10 mg Al^{3+} L^{-1} compared to zero level of aluminum in the nutrient solution.

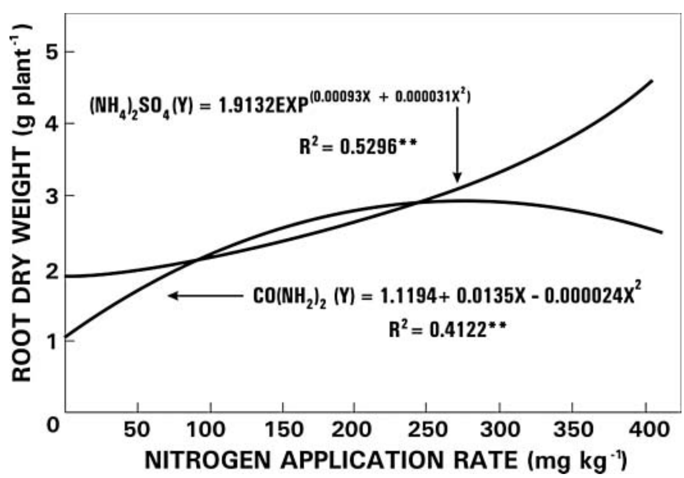

FIGURE 5 Relationship between nitrogen application rate by ammonium sulfate and urea and root dry weight of upland rice.

Shoot Dry Weight, Number of Panicles, Plant Height and Root Dry Weight

Shoot dry weight, panicle number and plant height increased significantly in a quadratic fashion with increasing N rate in the range of 0 to 400 mg kg^{-1} of soil by both the sources of N (Figures 2, 3, and 4). Based on regression equations, maximum shoot dry weight was obtained with the application of 476 mg N kg^{-1} by ammonium sulfate and 270 mg N kg^{-1} by urea. Maximum number of panicels was produced at 429 mg N kg^{-1} applied by ammonium sulfate and at 250 kg N applied by urea. Similarly, maximum plant height was achieved at 260 mg N kg^{-1} by ammonium sulfate and 258 mg N kg^{-1} by urea. Root dry weight increased quadratic exponential fashion with the application of N in the range of 0 to 400 mg kg^{-1} of soil by ammonium sulfate (Figure 5). The root weight, however, was increased in a quadric fashion and maximum value was obtained with the application of 281 mg N kg^{-1} of soil by urea (Figure 5). The improvement in shoot dry weight, number of panicles and root weight of rice was expected because Oxisols are deficient in N (Fageria and Baligar, 2005). Stone et al. (1999), Fageria (2000b), Fageria et al. (2006), and Fageria (2009) also reported the increase in upland rice growth and yield components of in Brazilian Oxisols.

Data in Figure 5 shows that response of root growth to N sources was different. Ammonium sulfate produced much higher root growth at the lower N rate (<75 mg kg^{-1}) and at the higher N rate (250 mg N kg^{-}). Fageria (1992) has reported improvement in root growth of rice with the application of N fertilization. Baligar et al. (1998) also reported that relative root weight of rice without N was 62% less than that of N applied at adequate level.

Grain Harvest Index, Grain Sterility and Thousand Grain Weight

Nitrogen source X N rate interaction for grain harvest index, grain sterility and thousand grain weigh was not significant. Hence, values of these parameters were presented across two N source (Table 1). Analysis of variance did not show significant effect on grain harvest index, however, regression equation showed that it increases significantly in a quadratic fashion with increasing N rate in the range of 0 to 400 mg kg^{-1}. Grain sterility and thousand grain weight were not affected significantly neither by N source or N rate treatments, except 1000 grain weight by N treatment. Based on regression equation, maximum grain harvest index was achieved at 225 mg N kg^{-1} of soil. Fageria and Baligar (2005) reported that grain harvest index values were 0.43 at zero N level and 0.50 at 400 mg N kg^{-1} across 19 upland rice genotypes. Thousand grain weight increased significantly in a quadratic fashion with increasing N rate in the range of 0 to 400 mg kg^{-1}. Maximum 1000 grain weight was achieved at 154 mg N kg^{-1}. Yoshida (1981) and Fageria

TABLE 1 Influence of N sources and rates on grain harvest index, grain sterility and thousand grain weight of upland rice. Values are across two N sources

N rate (mg kg^{-1})	Grain harvest index	Grain sterility (%)	1000 grain weight (g)
0	0.48	13.22	28.58
50	0.51	14.55	28.93
100	0.53	16.58	29.49
150	0.54	18.84	29.70
300	0.53	13.27	28.31
400	0.51	20.14	27.38
Average	0.52	16.10	28.73
F-Test			
N Source (S)	NS	NS	NS
N level (L)	NS	NS	**
S X L	NS	NS	NS
Regression analysis			
N rate vs. grain harvest index $(Y) = 0.4823 + 0.00054X - 0.0000012X^2$, $R^2 = 0.3422^*$			
N rate vs. grain sterility $(Y) = 14.3008 + 0.0133X - 0.0000091X^2$, $R^2 = 0.0615^{NS}$			
N rate vs. 1000 grain weight $(Y) = 28.6147 + 0.0111X - 0.000036X^2$, $R^2 = 0.5966^{**}$			

*, **, NS Significant at the 5 and 1% probability levels and non-significant, respectively.

(2007) reported that N is one of the most important nutrient in increasing yield component of rice, including 1000 grain weight.

Root Length, Contribution of Root, Shoot and Grain in Total Plant Weight

Interaction between N source and N rate was not significant for root length, root, shoot and grain contribution to total plant weight, hence average values across two N sources are presented (Table 2). Root length, root, shoot and grain contribution to total plant weight were significantly influenced only by N rate. Root length variation was about 48% due to N rate treatment. On an average root contributed 11% in the total plant weight, shoot contributed 43% of plant dry weight and grain contributed 46% of total plant weight. Hence, in modern rice cultivars photosynthetic partition in grain has significantly increased compared to old cultivars (Snyder and Carlson, 1984; Fageria, 2007). Fageria (1989) reported that in old cultivar of upland rice the contribution of roots in the total plant weight was 14%, contribution of shoot was 51% and contribution of grain in the total plant weight was 35%. In the modern high yield cultivar Fageria (1989) reported that contribution of roots in the total plant weight 10%, contribution of shoot 48% and contribution of grain 42% in the total plant weight.

Plant Growth and Yield Components Association with Grain Yield

Plant height, shoot dry weight, panicle number grain harvest index and root dry weight were significantly related to grain yield (Table 3). The

TABLE 2 Root length, contribution of roots, shoot and grain yield in the total plant weight as influenced by nitrogen rates. Values are averages across two N sources

N rate (mg kg^{-1})	Root length (cm)	Root contribution (%)	Shoot contribution (%)	Grain contribution (%)
0	28.50	15.99	43.59	40.42
50	24.38	10.57	44.27	45.16
100	27.63	9.60	42.66	47.75
150	23.75	9.17	41.95	48.88
300	25.63	9.60	42.24	48.17
400	32.38	11.13	43.71	45.16
Average	27.04	11.01	43.07	45.92
F-Test				
N source (S)	NS	NS	NS	NS
N rate (N)	**	**	NS	**
S X N	NS	NS	NS	NS

Regression analysis

N rate vs. root length $(Y) = 28.3445 - 0.0490X + 0.00014X^2$, $R^2 = 0.4783^{**}$
N rate vs. root contribution $(Y) = 14.7155 - 0.0584X - 0.00013X^2$, $R^2 = 0.4932^{**}$
N rate vs. shoot contribution $(Y) = 44.1797 - 0.0195X + 0.000045X^2$, $R^2 = 0.0692^{NS}$
N rate vs. grain contribution $(Y) = 41.1044 + 0.0781X - 0.00017X^2$, $R^2 = 0.5065^{**}$

**, ^{NS} Significant at the 1% probability level and non-significant, respectively.

variability in grain yield was 89% due to shoot dry weight, 82% due to plant height and panicle number, 64% due to root dry weight and 26% due to grain harvest index. Rice yield is determined by yield components and associated characters. Fageria et al. (1997) and Fageria (2007) reported that rice yield was highly correlated with shoot dry weight, panicle number and grain harvest index. Gravois and Helms (1992) reported that optimum rice yield could not be attained without optimum panicle density of uniform maturity. Similarly, Ottis and Talbert (2005) reported a high correlation ($R^2 > 0.85$) between yield and panicle density. The most important factor for the determination of spikelet number during reproductive growth stage is the amount of N absorbed, although photosynthesis also contributed in

TABLE 3 Relationship between plant growth and yield components (X) and grain yield (Y) of upland rice. Values are averages of two N sources

Variable	Regression equation	R^2
Plant height vs. grain yield	$Y = 0.7296\text{Exp.}(0.00226X + 0.00021X^2)$	0.8228^{**}
Shoot dry weight vs. grain yield	$Y = -4.8385 + 2.1852X - 0.0553X^2$	0.8932^{**}
Panicle number vs. grain yield	$Y = -6.5792 + 4.9425X$	0.8190^{**}
Grain harvest index vs. grain yield	$Y = 12884.89\text{ Exp.}(-34.76X + 40.35X^2)$	0.2597^{*}
1000 grain weight vs. grain yield	$Y = 623.2818 - 41.6005X + 0.7054X^2$	0.0855^{NS}
Grain sterility vs. grain yield	$Y = -0.7469 + 1.3541X - 0.0344X^2$	0.1428^{NS}
Root dry weight vs. grain yield	$Y = -8.5675 + 11.8641X - 1.4130X^2$	0.6362^{**}
Root length vs. grain yield	$Y = 35.2405 - 1.6870X + 0.0288X^2$	0.0119^{NS}

*, **, ^{NS} Significant at the 5 and 1% probability levels and non-significant, respectively.

the spikelet number determination (Ishii, 1995). Similarly, specific absorption rate of N per root dry weight during grain filling stage is the most important factor for achieving high rice productivity (Osaki et al., 1995).

CONCLUSIONS

Grain yield, yield components and growth characteristics of upland rice grown on Brazilian Oxisol were significantly influenced by N sources and N rates. Most of the responses related to these plant parameters were quadratic in fashion. At higher and lower N rate ammonium sulfate produced higher grain yield and most of the plant growth and yield components. At the intermediate N rate (125 to 275 mg N kg^{-1}) urea was slightly better compared to ammonium sulfate for grain production. The contribution of yield components and other plant growth characters was in the order of shoot dry weight > plant height, panicle number > root dry weight, grain harvest index. Root dry weight having higher association with grain yield compared to root length. Hence, this plant parameter should be given priority in measuring root components. The overall contribution of roots in the total plant weight was 11%, shoot contribution was 43% and grain contribution in the total plant weight was 46%.

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