Journal of Plant Nutrition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597277

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N. K. Fageria[a]; O. P. de Morais[a]; A.B. dos Santos[a]
[a] National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goiás, Brazil

Online publication date: 27 July 2010

To cite this Article Fageria, N. K. , de Morais, O. P. and dos Santos, A.B.(2010) 'NITROGEN USE EFFICIENCY IN UPLAND RICE GENOTYPES', Journal of Plant Nutrition, 33: 11, 1696 — 1711
To link to this Article: DOI: 10.1080/01904167.2010.496892
URL: http://dx.doi.org/10.1080/01904167.2010.496892

Journal of Plant Nutrition, 33:1696–1711, 2010

ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904167.2010.496892

NITROGEN USE EFFICIENCY IN UPLAND RICE GENOTYPES

N. K. Fageria, O. P. de Morais, and A. B. dos Santos
National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goiás, Brazil

□ *Nitrogen (N) deficiency is one of the most yield-limiting nutrients in upland rice growing regions word wide. A greenhouse experiment was conducted with the objective to evaluate nineteen upland rice (*Oryza sativa. *L.) genotypes for N use efficiency. The soil used in the experiment was an Oxisol and two N levels used were without N application (low level) and an application of 400 mg N kg^{-1} of soil (high level). Grain yield and yield components and N uptake parameters were significantly affected by N and genotype treatments. Regression analysis showed that plant height, shoot dry weight, number of panicles per pot, number of grains per panicle, grain harvest index, N uptake in shoot and grain were having significant positive relation with grain yield. Nitrogen concentration of 6.4 g kg^{-1} in the shoot is established as deficient level and 9.5 g kg^{-1} as sufficient level at harvest. Agronomic efficiency of N (grain yield/unit of N applied) and N utilization efficiency (physiological efficiency X apparent recovery efficiency) were significantly different among genotypes. These two N use efficiencies were having significant quadratic relationship with grain yield. Soil pH, exchangeable soil Ca and base saturation were having significantly positive association with grain yield. However, soil extractable phosphorus (P), potassium (K), hydrogen (H^+), aluminum (Al) and cation exchange capacity were having significantly negative association with grain yield.*

Keywords: agronomic efficiency, grain yield, physiological efficiency, yield components

INTRODUCTION

Rice is a staple food for more than 50% of the world population. A major part of rice production is produced and consumed in Asia (Fageria, 2001a). Asia, China, and India are major rice-producing and -consuming countries. There are two main ecosystems of rice, known as upland and lowland. Classification of rice ecosystems is based on environmental conditions. The main environmental conditions considered in classifying rice ecosystems are soil moisture regime, soil drainage, land topography and temperature (IRRI, 1984). Upland rice also known as aerobic rice is mainly grown in Latin

Received 27 November 2008; accepted 26 July 2009.
Address correspondence to N. K. Fageria, National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Santo Antônio de Goiás, GO, CEP 75375-000, Brazil. E-mail: fageria@cnpaf.embrapa.br

America, Africa and Asia. Upland rice is direct seeded in non-flooded, well drained soil on level to steeply sloping fields.

Upland rice yield is much lower than lowland-flooded rice. The main factors which are responsible for the lower upland rice yield are water deficit and use of low inputs by the farmers. These inputs include fertilizers, fungicides, insecticides, and herbicides. Use of low inputs is associated with drought risk and economic considerations. In spite of low yield, upland rice will continue to play an important role in rice growing regions due to lack of irrigation facilities and low production cost. Among essential plant nutrients, nitrogen (N) is one of the most yield limiting nutrients for upland rice production. The N deficiency in upland rice is related to low organic matter content of rice growing soils, soil acidity, soil erosion, use of low level of N fertilizers by farmers due to high cost of these fertilizers. Nitrogen deficiency is also related to low N use efficiency by the crop due to loss by leaching, volatilization, disnitrification and erosion (Fageria and Baligar, 2005). Hence, use of N efficient genotypes in conjugation with use of chemical fertilizers is an important complementary strategy in improving rice yield and reducing cost of production. Upland rice genotypes differ significantly in N uptake and utilization efficiency (Fageria et al., 1995b; Fageria, 2007). The objective of this study was to evaluate upland rice genotypes for N use efficiency and determine relationship between yield and yield attributing plant parameters.

MATERIALS AND METHODS

A greenhouse experiment was conducted at the National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goías, Goías, Brazil to evaluate N-use efficiency of 19 upland rice (*Oryza sativa L)* genotypes. The soil used in the experiment was an Oxisol (Typic Haplustox). It had the following chemical and textural properties before the application of N treatments: pH 5.1 (1:2.5 soil-water ratio), extractable phosphorus (P) 0.8 mg kg^{-1}, extractable potassium (K) 86 mg kg^{-1}, extractable calcium (Ca) 1.4 $cmol_c$ kg^{-1}, extractable magnesium (Mg) 0.6 $cmol_c$ kg^{-1}, extractable aluminum (Al) 0.2 $cmol_c$ kg^{-1}, extractable copper (Cu) 3.6 mg kg^{-1}, extractable zinc (Zn) 1.2 mg kg^{-1}, extractable iron (Fe) 76 mg kg^{-1}, extractable manganese (Mn) 45 mg kg^{-1}, and organic matter 20 g kg^{-1} of soil. Textural analysis values were 469 g kg^{-1} clay, 180 g kg^{-1} silt and 351 g kg^{-1} sand. Phosphorus and K were extracted by the Mehlich 1 extracting solution [0.05 M hydrochloric acid (HCl) + 0.0125 M sulfuric acid (H_2SO_4)]. Phosphorus was determined colorimetrically, and K by flame photometry. Calcium, Mg, and Al were extracted with 1 M potassium chloride (KCl). Aluminum was determined by titration with sodium hydroxide (NaOH), and Ca and Mg by titration with ethylenediaminetetraacetic acid (EDTA). Micronutrients were determined on a portion of the extract of P by atomic absorption spectrophotometry. Organic matter was determined by the Walkley-Black method, and textural analysis by pipette method. Soil analysis methods used in this study are described in a soil analysis manual published by EMBRAPA (1997).

The treatment consisted of two N levels, i.e., without N application (low) and an application of 400 mg N kg^{-1} (high) of soil using urea and 19 upland rice genotypes. The high level of N was applied in two equal split applications. One-half at sowing and the remaining half at active tillering (43 days after sowing). Genotypes used in the experiment were: CRO 97505, CNAs 8993, CNAs 8812, CNAs 8938, CNAs 8960, CNAs 8989, CNAs 8824, CNAs 8957, CRO 97422, CNAs 8817, CNAs 8934, CNAs 9852, CNAs 8950, CNA 8540, CNA 8711, CNA 8170, BRS Primavera, BRS Canastra, and BRS Carisma. These are the promising genotypes supplied by the breeders of the National Rice and Bean Research Center. A complete randomized design was used in a factorial arrangement, and treatments were replicated three times. The study was conducted in plastic pots, with 5 kg of soil in each. At the time of sowing, in addition to N treatments, each pot received a basal application of 200 mg P kg^{-1} as triple superphosphate and 200 mg K kg^{-1} as potassium chloride (KCl). These fertilizer rates were based on the recommendations of Fageria and Baligar (1997b). Each pot contained four plants, and soil moisture was maintained at about field capacity during the experimentation.

At maturity, number of panicles, dry matter of shoot, grain yield, number of grains per panicle, weight of 1000 grain, spikelet sterility, grain harvest index and N harvest index was determined. Dry plant material (shoot and grain) was dried in a forced-draft oven at about 70°C until of a constant weight, and milled. Total N in the plant tissue was determined with a Tecator 1016 digester and 1004 distilling unit according to method of Bremner and Mulvaney (1982). Grain harvest index and nitrogen harvest index were calculated by using the following formulas (Fageria et al., 1997):

Grain harvest index = Grian yield/Grain and shoot yield

Nitrogen harvest index = Nitrogen uptake in grain/Nitrogen uptake in grain and shoot

Definitions and N equations for calculating N use efficiencies are given in Table 1.

All data were analyzed by analysis of variance, and the F-test was used to determine treatment significance. Turkey's test was used to compare treatment means at 5% probability level. Appropriate regression equations were also used to further analysis of relations between grain yield and N uptake parameters and soil properties.

TABLE 1 Definitions and methods of calculating nutrient use efficiency

Nutrient efficiency	Definitions and formulas for calculation
Agronomic efficiency (AE)	The agronomic efficiency is defined as the economic production obtained per unit of nutrient applied. It can be calculated by: AE (mg mg^{-1}) = G_f–G_u/N_a, where G_f is the grain yield of the fertilized pot (mg), G_u is the grain yield of the unfertilized pot (mg), and N_a is the quantity of nutrient applied (mg)
Physiological efficiency (PE)	Physiological efficiency is defined as the biological yield obtained per unit of nutrient uptake. It can be calculated by: PE (mg mg^{-1}) = BY_f–BY_u/N_f–N_u, where, BY_f is the biological yield (grain plus straw) of the fertilized pot (mg), BY_u is the biological yield of the unfertilized plot (mg), N_f is the nutrient uptake (grain plus straw) of the fertilized pot, and N_u is the nutrient uptake (grain plus straw) of the unfertilized pot (mg)
Agrophysiological efficiency (APE)	Agrophysiological efficiency is defined as the economic production (grain yield in case of annual crops) obtained per unit of nutrient uptake. It can be calculated by: APE (mg mg^{-1}) = G_f–G_u/N_{uf}–N_{uu}, where, G_f is the grain yield of fertilized pot (mg), G_u is the grain yield of the unfertilized pot (mg), N_{uf} is the nutrient uptake (grain plus straw) of the fertilized pot (mg), N_{uu} is the nutrient uptake (grain plus straw) of unfertilized pot (mg)
Apparent recovery efficiency (ARE)	Apparent recovery efficiency is defined as the quantity of nutrient uptake per unit of nutrient applied. It can be calculated by: ARE (%) = (N_f–N_u/N_a) × 100, where, N_f is the nutrient uptake (grain plus straw) of the fertilized plot (mg), N_u is the nutrient uptake (grain plus straw) of the unfertilized pot (mg), and N_a is the quantity of nutrient applied (mg).
Utilization efficiency (EU)	Nutrient utilization efficiency is the product of physiological and apparent recovery efficiency. It can be calculated by: EU (mg mg^{-1}) = PE × ARE

RESULTS AND DISCUSSION

Plant height was significantly ($P < 0.01$) influenced by N and genotype treatments and across two N levels varied from 93 to 118 cm among genotypes with an average value of 103 cm (Table 2). There was a significant quadratic relationship between plant height (X) and grain yield ($Y = -196.3034 + 3.2542X - 0.0097X^2$, $R^2 = 0.65^{**}$). Hence, grain yield increases with increasing plant height but there is a limit of this increase. When plant height is too short it produces less dry matter and when too high it may lodge and less responsive to N fertilization (Yoshida, 1981). This means intermediate plant height is a better compromise and this is confirmed by the highest grain yield producing genotype CNAs 8993 (at high N level) that did not have the highest plant height but this genotype had an intermediate plant height. Shoot dry weight was not affected significantly among genotypes at low N level. However, Shoot dry weight of 19 genotypes was significantly ($P < 0.01$) influenced by high N level and varied from 44.4 to 75.8 g per pot at the

TABLE 2 Plant height across two N levels and shoot dry weight and grain yield at two N levels

		Shoot dry weight (g pot^{-1})		Grain yield (g pot^{-1})	
Genotype	Plant height (cm) across two N levels	Low N level	High N level	Low N level	High N level
CRO 97505	106cde	15.7a	53.8defg	14.2a	61.2ab
CNAs 8993	104cde	14.9a	52.3defg	16.1a	69.6a
CNAs 8812	93g	17.1a	62.8bcd	12.6a	60.9*ab*
CNAs 8938	99efg	13.9a	52.2defg	12.0a	55.6ab
CNAs 8960	112abc	14.9a	46.1defg	11.9a	55.3ab
CNAs 8989	99efg	14.5a	49.7efg	13.7a	63.2ab
CNAs 8824	94g	14.1a	47.0fg	12.9a	46.9ab
CNAs 8957	105cde	18.7a	44.4g	12.6a	57.3ab
CRO 97422	108bcd	16.4a	49.9efg	10.8a	50.5ab
CNAs 8817	109bcd	15.2a	56.0cdef	15.9a	51.7ab
CNAs 8934	105cde	16.0a	59.0bcde	10.3a	50.9ab
CNAs 9852	104cde	13.9a	44.9fg	8.4a	54.2ab
CNAs 8950	106cde	15.3a	48.6efg	11.4a	53.4ab
CNA 8540	93g	14.9a	58.9bcde	10.5a	54.8ab
CNA 8711	118a	16.9a	54.2defg	12.8a	51.5ab
CNA 8170	93g	17.3a	75.8a	12.1a	37.7c
BRS Primavera	115ab	14.5a	49.0efg	14.1a	59.3ab
BRS Canastra	94fg	16.2a	67.6ab	9.1a	52.5ab
BRS Carisma	102def	14.1a	66.7abc	8.9a	57.2ab
Average	103	15.5	54.7	12.1	54.9
F-Test					
N Level (N)	**		**		**
Genotype (G)	**		**		**
N × G	NS		**		**
CV (%)	4		7		12

Means followed by the same letter in the same column are not significantly different at the 5% probability level by Turkey's test.

**, NS Significant at the 1% probability level and nonsignificant, respectively.

high N level (Table 1). At high N level, shoot dry weight was 253% higher compared to low N level across genotypes. Shoot dry weight (X) showed highly significant quadratic relationship with grain yield ($Y = -27.7437 + 3.0163X - 0.0269X^2$, $R^2 = 0.92^{**}$). Yoshida (1981) reported that rice yield can be increased with increasing dry matter yield but relationship is not linear. Similarly, Kiuchi et al. (1966) reported that the increase of grain yield is certainly brought about by the increase in total dry matter yield, however at the same time it is found that the increment rate of the grain yield has a gradual decreasing tendency with the increase in the total dry matter yield. Fageria and Baligar (2001) also reported a quadratic relationship between rice grain yield and dry matter yield of shoot.

Grain yield was significantly ($P < 0.01$) influenced by N and genotypes treatments as well as by N X genotype interaction (Table 1). At low N level grain yield did not differ significantly among upland rice genotypes.

TABLE 3 Panicle number, panicle length and grain harvest index of nineteen lowland rice genotypes at two N levels

	Panicle no. pot^{-1}		Panicle length (cm)		Grain harvest index	
Genotype	Low N level	High N level	Low N level	High N level	Low N level	High N level
CRO 97505	8.0ab	17.7fg	17.9bcd	23.8abcd	0.48a	0.54abcd
CNAs 8993	8.3ab	22.0a–f	16.7de	19.5efgh	0.52a	0.57a
CNAs 8812	10.3a	28.0ab	16.2def	19.1fgh	0.43a	0.49abcd
CNAs 8938	7.7abc	20.3c–g	17.5cde	20.6defgh	0.43a	0.52abcd
CNAs 8960	6.0bc	15.0fg	20.8a	26.6a	0.45a	0.54abc
CNAs 8989	8.0ab	21.7a–g	16.3def	18.9fgh	0.49a	0.56abc
CNAs 8824	9.3ab	26.3abcd	17.6cde	19.2efgh	0.47a	0.50abcd
CNAs 8957	6.7abc	17.0fg	19.6abc	25.4abc	0.40a	0.56ab
CRO 97422	7.3abc	18.7efg	16.8de	23.9abcd	0.40a	0.50abcd
CNAs 8817	8.0ab	19.3defg	20.5ab	25.3abc	0.51a	0.48abcd
CNAs 8934	8.7ab	21.3b–g	17.6cde	21.6c–h	0.39a	0.46cd
CNAs 9852	3.7c	14.3g	18.6[a]bcd	22.6b–g	0.36a	0.55abc
CNAs 8950	6.7abc	19.7c–g	17.3cde	23.1a–e	0.43a	0.52abcd
CNA 8540	8.7ab	25.3a–e	13.9f	18.4h	0.41a	0.48abcd
CNA 8711	8.7ab	21.0b–g	17.4cde	22.8a–f	0.42a	0.49abcd
CNA 8170	10.0ab	29.0a	18.8[a]bcd	21.2d–h	0.41a	0.33e
BRS Primavera	7.7abc	17.0fg	19.7abc	25.7[a]b	0.49a	0.55abc
BRS Canastra	8.0ab	25.3a–e	17.6cde	20.9d–h	0.36a	0.44d
BRS Carisma	8.3ab	27.0abc	15.3ef	18.7gh	0.37a	0.47bcd
Average	7.9	21.4	17.7	22.0	0.43	0.50
F-Test						
N Level (N)	**		**			*
Genotype (G)	**		**			**
N × G	**		**			**
CV (%)	11		5			9

Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

*,** Significant at the 5 and 1% probability level, respectively.

However, at high N level, grain yield varied from 37.7 g per pot to 69.6 g per pot. The increase in grain yield with the application of 400 mg N kg^{-1} of soil was 354% as compared to treatment without N fertilization across 19 genotypes. This means that upland rice genotypes tested in this study were not able to extract sufficient N from low N level that can bring significant grain yield differentiation. Hence, all the genotypes tested were N inefficient at low N level. Fageria et al., (1995a; 1995b) reported significant yield differences among upland rice genotypes under low, medium and high fertility levels in Brazilian Oxisol under field conditions.

N and genotypes treatments and their interactions (Table 3) significantly affected panicle number per pot, panicle length, and grain harvest index. Panicle number varied from 3.7 to 10.3 per pot at low N level with an average value across genotypes of 7.9 per pot. Similarly, panicle number at higher N level varied from 14.3 to 28 per pot with an average value of 21.4 per pot. Overall, the increase in panicle number per pot was 171% with the application of N as compared to treatment without N fertilization. Number of panicles (X) were having significant ($P < 0.01$) quadratic relationship with grain yield ($Y = -32.9349 + 7.2697X - 0.1467X^2$, $R^2 = 0.81^{**}$). This means 81% variability in grain yield was accounted due to panicle number. Panicle number per unit area is considered as one of the important yield components in increasing upland rice yield (Fageria et al., 1997; Fageria, 2007, 2009). Panicle length varied from 13.9 to 20.8 cm with average value of 17.7 cm at low N level. Similarly, at high N level panicle length varied from 18.4 to 26.6 cm with an average value of 22 cm. Overall, the increase in panicle length at the higher N level was 24% compared with low N level. Panicle length (X) had a significant ($P < 0.01$) quadratic relationship with grain yield ($Y = -110.5796 + 9.9081X - 0.1299X^2$, 0.43^{**}). Yoshida (1981) reported that the number of spikelets or grain per unit area of rice crop is positively correlated with amount of N absorbed by the end of spikelet initiation stage or by flowering. Figure 1 shows the relationship between plant height, shoot dry weight, panicle number, panicle length and grain yield.

Grain harvest index varied from 0.36 to 0.52 with an average value of 0.43 at low N level and 0.33 to 0.57 with an average value of 0.50 at high N level (Table 3). Overall, there was a 16% increase in grain harvest index with the application of N as compared with control treatment. Grain harvest index is an important parameter in determining distribution of photosynthetic product between shoot and grain and consequently grain yield (Ishii, 1995). The review on the breeding progress for high yields indicates that the improvement of the harvest index has made substantial contributions to achieving high yields of rice (Chandler, 1969). Peng et al. (2000) determined the trend in the yield of rice cultivars/lines developed since 1966 at the International Rice Research Institute (IRRI), Philippines. These authors concluded that the increasing trend in yield of cultivars released before 1980 was mainly due to the improvement in grain harvest index (GHI), while an increase in total biomass was associated with yield trends for cultivars/lines developed after 1980. They also suggested that further increases in rice yield potential will likely occur through increasing biomass production rather than increasing GHI.

Kiniry et al. (2001) reported that the GHI varied greatly among cultivars, locations, seasons, and ecosystems, ranging from 0.35 to 0.62, indicating the importance of this variable for yield stimulation. Kiniry et al. (2001) also reported that yield variability among rice cultivars is highly dependent on grain harvest index. The importance of this variable is also confirmed when we compared grain yield of highest yielding genotype CNAs 8993 which had a grain harvest index of 0.57 and lowest yielding genotypes CNA 8170 had a harvest index of 0.33 at higher N level. This genotype (CNA 8170) had the highest number of panicles among all the genotypes tested. This means that there should be a balance among the entire yield attributing

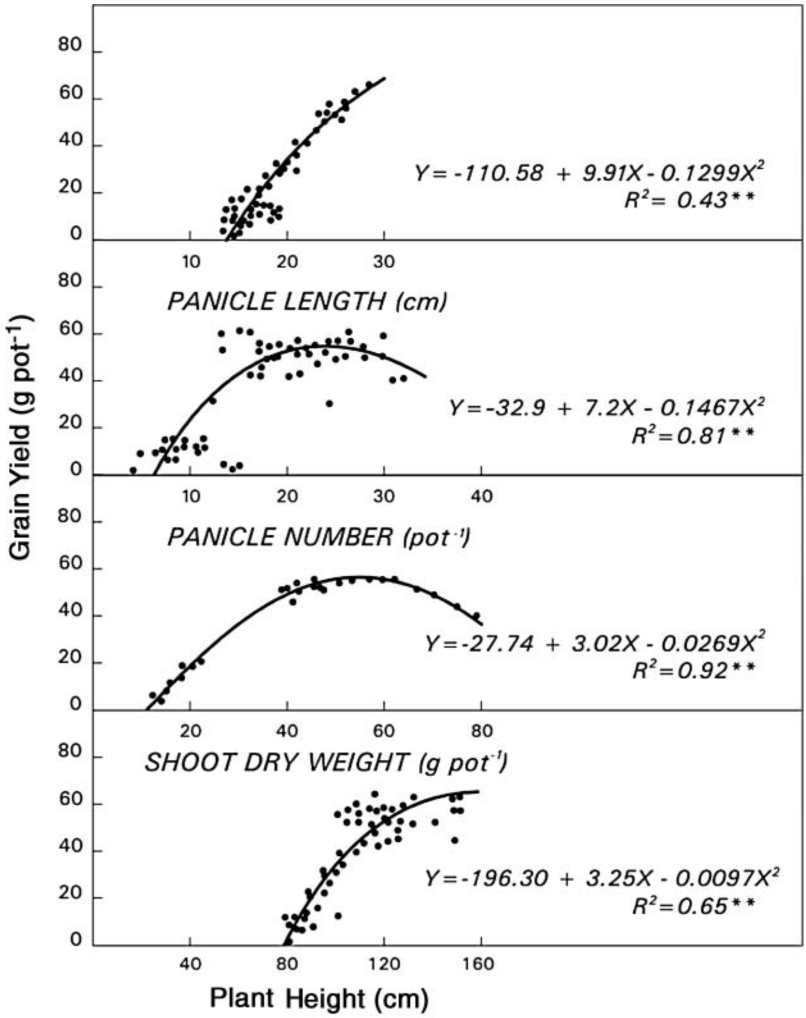

FIGURE 1 Relationship between plant height, shoot dry weight, panicle number, panicle length and grain yield of upland rice.

parameters of plant to obtain higher yield. Peng et al. (2000) reported that high yielding rice cultivars/lines developed at the IRRI from 1985 to 1995 were intermediate in canopy height, tillering capacity, and leaf area index. Cultivars in this group were able to maintain relatively high grain harvest index.

Nitrogen concentration in shoot and N uptake in shoot (N concentration in shoot X shoot dry weight) was significantly influenced by N and genotype treatments (Table 4). However, N concentration in grain was not influenced either by N or by genotype treatments. But N uptake in grain was only influenced by N treatment. Nitrogen concentration in shoot varied from 4.8 to 8.9 g kg^{-1} with an average value of 6.4 g kg^{-1} at low N level.

TABLE 4 Concentration and uptake of nitrogen in the shoot and grain of nineteen upland rice genotypes at two nitrogen levels

Genotype	N conc. in shoot ($g\ kg^{-1}$)		N uptake in shoot ($mg\ pot^{-1}$)		N conc. in grain ($g\ kg^{-1}$) across two N levels	N uptake in grain ($mg\ pot^{-1}$) across two N levels
	Low N level	High N level	Low N level	High N Level		
CRO 97505	6.3abc	8.7ab	100.0abc	473.1a	10.9a	409.0a
CNAs 8993	6.3abc	7.0ab	93.5abc	363.4a	11.3a	513.5a
CNAs 8812	6.9abc	9.2ab	117.7abc	574.5a	13.3a	510.3a
CNAs 8938	5.7bc	11.3^{a}b	79.2bc	588.1a	11.9a	386.3a
CNAs 8960	6.0bc	10.4ab	89.2bc	478.3a	12.4a	429.7a
CNAs 8989	6.3abc	12.8a	91.2bc	635.1a	11.7a	470.9a
CNAs 8824	4.9*c*	9.8ab	68.2c	456.9a	12.6a	417.4a
CNAs 8957	5.4bc	10.8ab	100.5abc	481.1a	12.8a	465.5a
CRO 97422	6.7abc	9.8ab	109.1abc	491.1a	12.5a	387.3a
CNAs 8817	5.6bc	10.5ab	84.9bc	581.9a	12.1a	444.0a
CNAs 8934	8.9a	10.5ab	142.3a	620.2a	11.5a	370.5a
CNAs 9852	7.2abc	10.5ab	100.7abc	473.9a	11.3a	385.3a
CNAs 8950	7.6ab	9.1ab	115.4abc	434.6a	12.6a	422.0a
CNA 8540	4.8*c*	9.8ab	72.1c	578.0a	12.3a	405.3a
CNA 8711	6.6abc	10.0ab	111.8abc	541.8a	12.5a	414.9a
CNA 8170	5.7bc	8.7ab	99.0abc	654.3a	11.1a	298.1a
BRS Primavera	6.0bc	7.2ab	87.1bc	352.2a	12.5a	484.8a
BRS Canastra	7.6ab	5.7b	123.3abc	382.1a	12.1a	381.5a
BRS Carisma	6.7abc	8.3ab	94.4abc	552.4a	12.8a	439.4a
Average	6.4	9.5	98.9	511.2	12.1	422.9
F-Test						
N Level (N)	*		**		NS	**
Genotype (G)	**		**		NS	NS
N × G	**		**		NS	NS
CV (%)	16		21		14	25

Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

*, **, NS Significant at the 5 and 1% probability level and nonsignificant, respectively.

All the genotypes showed visual N deficiency symptoms at low N level. This means average N concentration of 6.4 g kg^{-1} in shoot can be considered as deficient level in upland rice. At higher N level, N concentration in shoot varied from 5.7 to 12.8 g kg^{-1} with an average value of 9.5 g kg^{-1}. Visual N deficiency symptoms were not observed in any genotypes at higher N level. Hence, average value of 9.5 g N kg^{-1} can be taken as an adequate concentration in the shoot of upland rice at harvest. Fageria (1998) reported adequate concentrations for maximum yield about 8.7 g kg^{-1} in the shoot of upland rice under field condition at harvest. The slightly higher value of N concentration in the shoot of present study may be due to use of different genotypes. Nitrogen concentration in the shoot had a significant quadratic association with grain yield ($Y = -38.3532 + 126.1739X - 41.0378X^2$,

$R^2 = 0.34^{**}$). This means improving N concentration in upland rice genotypes can improve grain yield.

In the grain, N concentration was 11.3 g kg^{-1} at low N level and 12.8 g kg^{-1} at high N level across the 19 upland rice genotypes (data not presented). These concentrations can be considered deficient and sufficient for upland rice, respectively. Cassman et al. (2002) reported that N concentration of about 12 g kg^{-1} is desired in the grain of rice for optimal cooking and eating quality. Nitrogen concentration was higher in grain compared to shoot. Nitrogen concentration in the grain of rice is always higher than the stover (Kiniry et al., 2001). However, there was less variation in N concentration in grain among genotypes compared to N concentration in the shoot. Nitrogen concentration in grain had a highly significant positive association with grain yield ($r = 0.31^{**}$). Hence, increasing N concentration in grain can increase upland rice grain yield. Nitrogen uptake in shoot varied from 72.1 to 142.3 mg pot^{-1} at low N level with an average value of 98.9 mg pot^{-1}. At higher N level, N uptake in the shoot varied from 352.2 to 654.3 mg pot^{-1} with an average value of 511.2 mg pot^{-1}. Uptake of N in grain varied from 298.1 to 513.5 mg pot^{-1} across two N levels. Uptake of N in the shoot and grain followed dry matter yield of these two plant parameters. Uptake of N in shoot ($r = 0.85^{**}$) as well as in grain (0.93^{**}) had a highly significant associated with grain yield. This indicates that increasing N accumulation in shoot as well as grain can improve upland rice yield. However, influence of N accumulation in grain is higher compared to shoot.

Nitrogen use efficiencies defined in Table 1 were calculated for genotypes (Table 5). Agronomical efficiency (AE) and utilization (EU) were significantly different among genotypes. Physiological efficiency (PE), agrophysiological efficiency (APE) and apparent recovery efficiency (ARE) were also varied among genotypes, however difference was statistically not significant. The AE varied from 12.8 to 26.7 mg grain produced per mg N applied with an average value of 21.4 mg grain produced per mg of N applied. Average value across the genotypes of PE was 86.6 mg dry matter production (grain plus straw) per mg N accumulated in grain and straw. Average value of APE was 45.2 mg grain produced per mg N accumulated in grain and straw. Fageria and Barbosa Filho (2001) determined APE in eight lowland rice genotypes and reported average value of 45.5 mg grain produced per mg N accumulated in the grain and straw. Hence, APE of lowland and upland rice is comparable. The average ARE was 49.2%. The ARE in lowland rice is reported to be in the range of 31 to 40% in major rice growing regions of the world (Cassman et al. 2002). Fageria and Baligar (2001) reported that average ARE in lowland rice in Brazilian Inceptisol was 39%. This means ARE in upland rice is higher compared to lowland rice. The highest grain yield producing genotype CNAs 8993 had the highest AE, whereas the lowest yielding genotype CNA 8170 had the lowest AE. The genotype CNAs 8992 also had the highest PE and APE and reasonably good values of ARE and EU.

TABLE 5 Nitrogen use efficiency of nineteen upland rice genotypes

Genotype	Agronomical efficiency (mg mg^{-1})	Physiological efficiency (mg mg^{-1})	Agrophysiological efficiency (mg mg^{-1})	Apparent recovery efficiency (%)	Utilization efficiency (mg mg^{-1})
CRO 97505	23.5ab	100.2a	55.4a	43.5a	42.5ab
CNAs 8993	26.7a	101.4a	59.0a	47.8a	45.5ab
CNAs 8812	24.2ab	80.5a	41.3a	58.2a	47.0ab
CNAs 8938	21.8ab	87.8a	46.3a	48.7a	40.9ab
CNAs 8960	21.7ab	79.3a	46.1a	48.3a	37.3ab
CNAs 8989	24.8aab	72.3a	42.3a	59.3a	42.4ab
CNAs 8824	17.0ab	73.7a	36.7a	47.0a	33.5b
CNAs 8957	22.4ab	72.3a	46.3a	50.7a	35.2ab
CRO 97422	19.8ab	85.7a	47.1a	45.0a	36.6ab
CNAs 8817	17.9ab	72.7a	33.6a	53.2a	38.3ab
CNAs 8934	20.3ab	83.3a	40.5a	50.2a	41.8ab
CNAs 9852	22.9ab	81.7a	48.9a	47.7a	38.4ab
CNAs 8950	21.0ab	88.5a	49.9a	44.7a	37.6ab
CNA 8540	22.2ab	89.7a	45.2a	53.5a	44.1ab
CNA 8711	19.4ab	79.2a	40.0a	48.1a	38.0ab
CNA 8170	12.8*b*	92.8a	28.0a	45.4a	42.0ab
BRS Primavera	22.6ab	89.8a	51.2a	45.8a	39.9ab
BRS Canastra	21.7ab	125.7a	57.7a	40.6a	47.4ab
BRS Carisma	24.2ab	89.6a	42.8a	56.2a	50.5a
Average	21.4	86.6	45.2	49.2	41.0
F-Test					
Genotype	*	NS	NS	NS	**
CV (%)	17	23	26	24	12

Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

$^{*, **, NS}$ Significant at the 5 and 1% probability level and nonsignificant, respectively.

The AE had a highly significant ($P < 0.01$) relationship with grain yield ($r = 0.77^{**}$). The PE was not related significantly with grain yield, however APE had a highly significant ($P < 0.01$) relationship with grain yield ($r = 0.37^{**}$). The ARE ($r = 0.31^{*}$) and UE ($r = 0.40^{**}$) were also associated significantly with grain yield. Figure 2 shows relationship between grain yield and different U-use efficiencies for upland rice genotypes.

Selected soil chemical properties of 10 genotypes selected on the basis of highest, medium and lowest grain yield production were determined at harvest. Soil pH and extractable soil P were significantly influenced by N level as well as genotype treatments (Table 6). However, exchangeable Mg in the soil was only affected significantly by genotype treatment. In addition, exchangeable Ca, K and H + Al, cation exchange capacity (CEC) and base saturation were significantly influenced by N level (Table 7). Soil pH varied from 6.3 to 6.6 with an average value of 6.4 among genotypes. The variation in pH among genotypes may be related to unbalanced uptake of cations and anions. When more cations are absorbed, pH of the growth medium decreases due to release of H^+ ions by the roots. While anions absorption

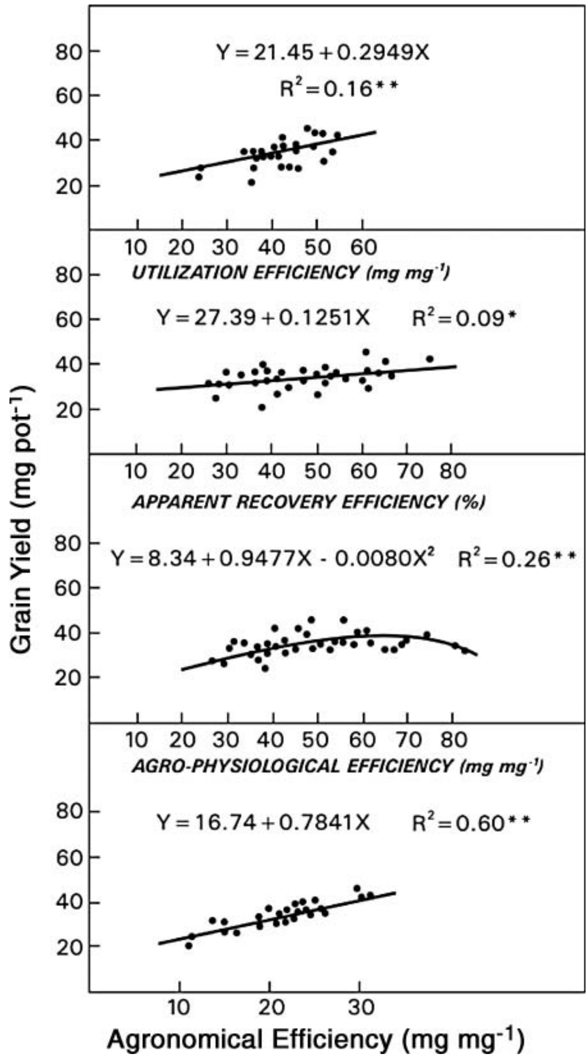

FIGURE 2 Relationship between different N use efficiencies and grain yield.

is higher than cations, OH^- or HCO_3^- ions are released and pH increases (Moore, 1974).

Variation in soil Mg among genotypes was 11.6 to 13.6 with an average value of 12.5. Similarly, variation in extractable soil P was 21.9 to 40.2 mg dm^{-3} with an average value of 31.7 mg dm^{-3}. Fageria and Morais (1987) and Fageria and Baligar (1997a) have reported variation in upland rice genotypes for extraction of Mg and P in Oxisols.

Application of 400 mg N kg^{-1} of soil increases soil pH from 6.2 to 6.6 compared to control treatment or without N application treatment across 10 genotypes (Table 7). The increase in pH may be related to use of urea as N

TABLE 6 Soil pH, extractable soil Mg and P determined after harvest of ten upland rice genotypes

Genotype	pH in water	Mg (mmol dm^{-3})	P (mg dm^{-3})
CRO 97505	6.3c	11.5c	38.9ad
CNAs 8993	6.4abc	12.7abc	25.6bc
CNAs 8812	6.4abc	12.3abc	31.9abcd
CNAs 8989	6.4abc	11.6ac	34.2abcd
CNAs 8824	6.6a	12.1abc	39.9a
CRO 97422	6.4abc	11.7ac	40.2a
CNA 8170	6.5ab	13.5ab	25.2bc
BRS Primavera	6.3*c*	12.2abc	31.0abcd
BRS Canastra	6.5ab	13.6ab	28.6bcd
BRS Carisma	6.5ab	14.1b	21.9c
Average	6.4	12.5	31.7
F-Test			
N Level (N)	**	NS	**
Genotype (G)	*	*	**
N × G	NS	NS	NS
CV(%)	3	12	26

Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

*, **, NS Significant at the 5 and 1% probability level and nonsignificant, respectively.

fertilizer. Urea hydrolysis generates alkalinity by the reaction: $CO(NH_2)_2 + 2H_2O \Leftrightarrow HCO_3^- + NH_4^+ + NH_3$ (Gaudin and Dupuy, 1999). The formation of HCO_3^- and NH_3 ions is responsible for increasing soil pH. Soil pH had a highly significant positive association with grain yield across 10 genotypes ($r = 0.64^{**}$). This means increasing soil pH increases grain yield of upland rice genotypes. Although, upland rice is tolerant to soil acidity (Fageria, 2001b), a positive quadratic relationship was reported with soil pH and grain yield of upland rice genotypes in Brazilian Oxisol (Fageria, 2000). Fageria (2001c) reported adequate value of 12 mmol Mg^{2+} dm^{-3} in Brazilian Oxisol for upland rice. Similarly, Fageria (1990) determined 30 to 40 mg P dm^{-3}

TABLE 7 Selected soil chemical properties as influenced by two applied N levels across 10 upland rice genotypes determined after harvest

Soil chemical property	Low N (0 mg kg^{-1})	High N (400 mg kg^{-1})
pH in water	6.2b	6.6a
Ca (mmol dm^{-3})	25.8b	29.2a
P (mg dm^{-3})	35.1a	28.4b
K (mg dm^{-3})	201.7a	37.5b
H + Al (mmol dm^{-3})	31.7a	27.2b
CEC (mmol dm^{-3})	75.1a	69.9b
Base saturation (%)	61.2a	57.8b

Means followed by the same letter under two N levels are not significantly different at the 5% probability level by Tukey's test.

for 100% relative grain yield of three upland rice cultivars under greenhouse conditions. This means exchangeable Mg^{2+} and available P were sufficient in the soil for upland rice genotypes. This hypothesis was also confirmed by nonsignificant correlation of exchangeable Mg^{2+} ($r = 0.01$) with grain yield and highly significant negative correlation ($r = -0.93^{**}$) with available P and grain yield.

Exchangeable soil Ca^{2+} significantly increased with the application of N, whereas available P, K, H + Al, CEC and base saturation decreased with increase N level in the soil (Table 7). The increase in exchangeable Ca^{2+} and decrease in available P with increasing N level may be related to increase in soil pH. Fageria (1984) reported that available P in Oxisol of cerrado region of Brazil decreased when soil pH was raised more than 6.2 due to formation of insoluble calcium phosphate. Exchangeable soil Ca^{2+} had a significant positive correlation ($r = 0.45^{*}$) with grain yield. Fageria (1984) reported that upland rice genotypes grain yield increased with the application of calcium carbonate but increase varied with genotype to genotype. The decrease in soil K at higher level of N was very drastic compared to K level of control treatment. Potassium had a significant negative correlation (-0.93^{**}) with grain yield. This means that it was not deficient in the soil. The decrease in K is related to high uptake rate of K by rice genotypes with the increase of yield at high N level. Potassium uptake was highest by upland rice compared to all other essential macronutrients (Fageria, 2001a). The decrease in H + Al, CEC and base saturation at high N level is associated with decrease in H + Al and K with increasing pH. The H + Al ($r = -0.46^{**}$) and CEC ($r = -0.44^{**}$) were having significant negative correlation with grain yield.

CONCLUSIONS

Upland rice genotypes responded differently to applied N at higher N level. However, at lower N level, grain yield and most of the yield components did not differ significantly. This suggests that in selection upland rice genotypes use of adequate N rate is essential. Plant height, shoot dry matter, panicle number, panicle length, grain harvest index, N concentration in shoot and grain, and N uptake in shoot and grain were having significant positive relationship with grain yield. These plant parameters were also significantly affected by N as well as genotypes treatments. Hence, it is possible to manipulate these plant parameters in favor of higher grain yield by using adequate N rate or planting N efficient genotypes. Based on results of this study it can be concluded that upland rice average yield can substantially be increased with planting N efficient genotypes along with improved crop management practices.

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