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*Full Length Research Paper*

# Genetic variation in nitrogen efficiency among cultivars of irrigated rice in Senegal

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**Due to increasing fertiliser costs as well as environmental concerns, N-efficiency became an attractive breeding topic. Genotypes can be considered as N-efficient if they realise an above average yield at low N level or if they convert high N input comparatively better into yield than other genotypes. To evaluate potential of *Oryza sativa* L. in nitrogen use efficiency compared to *Oryza glaberrima* Steudt., a two years field experiment was conducted. Twelve *O. sativa* genotypes were tested in a split-plot design with two N-levels (without N fertiliser and with 150 kg N/ha). For comparison, one genotype of African rice, *O. glaberrima*, was included in the experiment. Variability about grain yield at harvest and N-uptake was observed between *O. sativa* and *O. glaberrima* and within *O. sativa* genotypes. *O. glaberrima* had lower yield as *O. sativa*. In low N-level, a close relationship between total N-uptake in plant and grain yield was observed. In high N-level, no correlation was observed. An effect of *O. glaberrima* genotype on the variance component GN was demonstrated. Variation in N uptake and in N utilisation efficiency depends on N fertilisation. At low N level variation in N uptake were higher than at high N level. At the opposite, variations in utilisation efficiency were lower without fertilisation than with fertilisation. Genotypes Farox 304 and Farox 239 gave best yields at high N input as well as under low N input conditions. At low N input, variation in uptake efficiency was higher than variation in utilisation efficiency. In contrary at high N level, variation in utilisation efficiency was higher than variation in uptake efficiency. Improving N-efficient genotype through classical breeding or using biotechnology linked with innovative agronomic management could be exciting prospects to improve N use efficiency.**

**Key words:** Fertiliser, environment, nitrogen, N-uptake, N-efficiency, breeding, genotypes, yield, *Oryza sativa* L., *Oryza gaberrima* Steudt.

## INTRODUCTION

Irrigated rice is an intensive crop system with the use of high amounts of nitrogen (N) inorganic fertilisation (Cakmak, 2001; Fischer, 2000). Nitrogen is the most critical input that limits rice productivity (Sahu et al., 1997, Shrawat et al., 2008). By the increase of fertiliser costs, and due to environmental impact, research to improve nitrogen efficiency becomes an important breeding challenge (Dawson et al., 2008; Delmer, 2005; Hoisington et al., 1999). Genetic selection is generally conducted with high fertiliser inputs; and high yielding varieties of corn, wheat, and rice released during the Green Revolution were selected to respond to high N inputs (Earl and Ausebel, 1983). This can mask differences among genotypes in efficiency to accumulate and utilise nitrogen to produce grain (Kamprah et al., 1982, cited by Rauna and Johnson, 1999). Consequently, continued efforts are needed to include plant selection under low N – supply (Bi et al., 2009; Dawson et al., 2008, Balcha et al., 2006, Gallais and Coque, 2005), something not often considered as priority by plant breeders, and not characteristic for yield tests on

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**Table 1.** Description of varieties tested in the present experiment.

| No | Varieties | Origin | Pedigree | Species |
|---|---|---|---|---|
| 1 | Sahel 108 | IRRI | IR Bos/Babawee/IR 36 | *Oryza sativa* |
| 2 | IKP | Taiwan | DGWG/Tall indica | *O. sativa* |
| 3 | Farox 304-4-1-2 | Nigeria | | *O. sativa* |
| 4 | IR 31851 | IRRI | IR1749-5-4-3-3/IR2415-90-4-3-2 | *O. sativa* |
| 5 | Jaya | Indien | TN1 / T141 | *O. sativa* |
| 6 | ITA 344 | IITA | ITA 312 / UPLRi 7 | *O. sativa* |
| 7 | Sahel 201 | Sri Lanka | IR2071-586 / Bg 6812 | *O. sativa* |
| 8 | Sahel 202 | IITA | Tox 496-3696 / Tox 711-Bg 6812 | *O. sativa* |
| 9 | ITA 123 | IITA | Mutant OS 6 | *O. sativa* |
| 10 | ECIA31-6066 | Kuba | | *O. sativa* |
| 11 | DR 31 | Pakistan | IR 38 / IET 1039-PD3-PPD5-PD2 | *O. sativa* |
| 12 | Farox 239-3-3-2 | Nigeria | Faro 12 / IR 28 | *O. sativa* |
| 13 | 6202 Tog | WARDA | | *O. glaberrima* |

**IRRI,** International Rice Research Institute; **IITA,** International Institute for Tropical Agriculture; **WARDA,** West African Rice Research Development Association or AfricaRice.

experimental stations (Rauna and Johnson, 1999). Nitrogen efficiency is defined in various ways in the literature. A genotype can be considered as N-efficient because it realises an above average yield at suboptimal N level (Graham, 1984). On the other hand a genotype can be called N-efficient if it converts high N input into yield comparatively better than other genotypes (Sattelmacher et al., 1994). Moll et al. (1982) defined nitrogen use efficiency as grain yield per unit N supply. Efficiency of utilisation of N can be defined as grain yield per unit N uptake (Muchow, 1998). Genetic variation in nutrient efficiency is based on two components (Sattelmacher et al., 1994; Moll et al., 1982): (i) on differences in efficiency of nutrient uptake (uptake efficiency) and (ii) on differences in efficiency to use absorbed nutrients for yield formation (utilisation efficiency).

In West Africa, the traditionally grown *Oryza glaberrima* is increasingly beeing replaced by *Oryza sativa* during the last decades. Field acreage of *O. sativa*, cultivated rice from Asia, increases supported by regional advancement programs. Asian rice has often higher yields under optimal conditions than traditionally cultivated African rice. But *O. sativa* species have limited resistance to weed, disease and many other stress conditions limiting yield. In contrary, *O. glaberrima* is regarded as an important genetic resource for biotic stress factors (Jones et al., 1996) because it has many useful traits such as weed competitiveness, drought tolerance and ability to grow under low input conditions (Sarla and Mallikarjuna, 2005). *O. glaberrima* was found to have different pattern of blast resistance (Silue et Notteghem, 1991 cited by Ghesquiere et al., 1997), good to very high levels of resistance of Rice Yellow Mottle Virus (RYMV) (Attere and Fatokun, 1983; John et al., 1994) and is resistant to many insects. *O. glaberrima* also possesses useful traits in terms of tolerance to abiotic stresses such as acidity, iron toxicity and drought. Moreover, its early, rapid and vigorous vegetative growth can contribute to better control of weeds in rice fields (John et al., 1994). It is interesting to evaluate potential of *O. glaberrima* particularly for nitrogen-use efficiency comparatively to *O. sativa*. Objectives of the present study are the analysis of the genetic variation in grain yield and N-efficiency among 12 varieties of *Oryza sativa* from different regions and one *Oryza glaberrima* genotype included for comparison. Genotypes were grown in field experiments at two N-levels (without N input and with 150 kg N/ha). Grain yield at harvest, yield components, and N-use efficiency were measured and correlations among traits were investigated.

## MATERIALS AND METHODS

A two years experiment was conducted at the Africa Rice station in Ndiaye, Senegal (16°14 x 27N) from July to November 1998 which is the wet season (first year experiment) and from February to May 1999 which is the hot dry season (second year experiment). In both seasons fields are irrigated until start of maturity. The design was a randomised split plot with four replications. The whole plot were two nitrogen treatments (N0 = 0 kg N/ha and N1 = 150 kg of N/ha) and the sub-plot were thirteen rice genotypes (12 *Oryza sativa* + 1 *Oryza glaberrima*) (Table 1). The plot size was 3 x 4 m and the distance between rows was 20 cm. N fertilisation was applied at three developmental stages, with 60 kg N/ha after planting, 60 kg N/ha after panicle initiation and 30 kg N/ha after flowering. Yield was measured from an area of 3.36 $m^2$ in the centre of the plot. For yield components 8 randomised plants for every genotype were harvested. For the measure of N concentration in straw and in seed a sample of 8 plants was milled and analysed by the Kjeldahl Method. The method of Moll et al. (1982) was used to analyse nitrogen efficiency and to partition nitrogen efficiency into the components uptake und utilisation efficiency. Moll et al. (1982) subdivided N use efficiency into the two main components: efficiency of absorption (N uptake efficiency), that is total N in plant

**Table 2.** Mean value of the *O. sativa* cultivars at two N levels.

| Traits | N0 | N150 | F |
|---|---|---|---|
| Tiller number | 78.25 | 123.73 | ** |
| Panicle number | 73.78 | 117.39 | ** |
| Panicle weight (g) | 170.36 | 279 | ** |
| Grain yield (t/ha) | 3.94 | 7.27 | ** |
| Harvest Index (HI) | 0.49 | 0.46 | NS |
| Straw (t/ha) | 6.64 | 12.59 | ** |
| TSW (g) | 27.14 | 26.48 | NS |
| Time to maturity (day) | 122.73 | 130.55 | ** |
| Plant height (cm) | 82.21 | 90.37 | ** |
| N concentration in straw (Nstra %) | 0.57 | 0.74 | ** |
| N concentration in seed (Nsee %) | 0.95 | 1.19 | ** |
| Protein content | 5.93 | 7.45 | ** |
| N in straw (kg/ha) | 37.84 | 94.75 | ** |
| N in seed (kg/ha) | 37.96 | 86.23 | ** |
| N in plant (kg/ha) | 75.81 | 181.99 | ** |

**, *, +: Statistically significant difference at P=0.01, P=0.05, P=0.10; F-test in ANOVA.

at maturity per N supply, and the efficiency with which the N absorbed is utilised to produce grain (N utilisation efficiency), that is grain yield per total N in plant at maturity. Nitrogen efficiency, uptake efficiency and utilisation efficiency are expressed as follows:

Nitrogen use efficiency = Gw/Ns
Uptake efficiency = Nt/Ns
Utilisation efficiency = Gw/Nt
Nitrogen efficiency = Uptake efficiency x Utilisation efficiency
Gw/Ns = (Nt/Ns)(Gw/Nt)
Gw = Grain yield (kg/ha)
Ns = N supply (kg/ha)
Nt = N content in plant (kg/ha)

In addition, a partitioning of variation in N efficiency into uptake efficiency and utilisation efficiency at low and high N- level were calculated according to Moll et al. (1982).

N efficiency Y = log (Gw/Ns)
Uptake efficiency X1 = log(Nt/Ns)
Utilisation efficiency X2 = log(Gw/Nt)
Variance of N efficiency VAR (Y) = Covariance (YX1) + Covariance (YX2)
Uptake efficiency A=Covariance (YX1) / VAR (Y)
Utilisation efficiency U = Covariance (YX2) / VAR (Y)

In our studies, N efficiency, N uptake efficiency and N utilisation efficiency (Moll et al., 1982) were calculated, separately for N=0 and for N=150 kg N/ha, from the yield and total N content in plant. Ns was estimated in N0 from the cultivar with maximum amount of N uptake as 100 kg/ha and in N150 as 250 kg/ha. *O. glaberrima* was not included, and one outlaying value (Farox 304 in N0) was excluded. Soil samples were taken before testing begins to analyze the nitrogen content. Unfortunately data were not included. However the experiments were conducted in a field that has remained for two seasons without nitrogen. Data were analysed statistically using Plabstat (Plant Breeding Statistics) (Utz, 1997).

## RESULTS

Mean value of yield and yield components of *O. sativa* cultivars are summarised in Table 2. Difference between N treatments was noted for all traits. Except for harvest index (HI) and thousand seed weight (TSW), yield and yield components presented higher values at the high level of N supply. An overview over the results from the analyses of variance (ANOVA) for all traits is represented in Table 3. ANOVA showed significant differences among genotypes for all traits. A wide range of variation was exhibited for all traits. Significant effect of Genotype (G) and the N-fertilisation was also noted. Analysis of variance for yield analysing all genotypes including *O. glaberrima* showed highly significance of variance components N, NS, G, GS and GN (Table 4). Variance component GN (0.44) was nearly half as large as the genotypic variance (0.94). If *O. sativa* genotypes are analysed alone, genetic variance is smaller and no significant GN interaction can be observed (Table 4). Variance components for yield and yield components with only *O. sativa* genotypes showed significant variation for N concentration in straw and in seed, and protein content for the component G, GN, GS and GNS (Table 5).

The characters N straw yield, N grain yield and N content in plant presented also significant variation for the same component. Grain yield at low and high N input at the two seasons (Wet Season + Hot dry Season) is summarised in Figure 1. Difference in yield production between *O. sativa* and *O. glaberrima* was observed. *O. sativa* genotypes showed much higher yield than *O. glaberrima* genotypes at both N levels. Even within *O. sativa* genotypes there is a large variability in the yield

**Table 3.** F-value from analysis of variance for season (S), nitrogen level (N), genotype (G) and the respective interactions.

| Traits | S | N | NS | G | GS | GN | GNS |
|---|---|---|---|---|---|---|---|
| Tiller number | 15.03** | 106.83** | 1.26 | 5.79** | 5.46** | 0.70 | 1.21 |
| Panicle number | 17.20** | 84.40** | 3.21 | 5.00** | 4.76** | 1.13 | 0.68 |
| Panicle weight (g) | 7.55** | 67.88** | 16.50** | 6.76** | 2.37** | 2.13* | 0.46 |
| Yield(t/ha) | 0.19 | 80.74** | 37.68** | 12.52** | 3.52** | 3.71** | 0.98 |
| HI | 3.21+ | 3.78+ | 4.54* | 7.48** | 1.28 | 2.33** | 0.83 |
| Straw (t/ha) | 13.73** | 134.67** | 0.55 | 3.91** | 1.89* | 1.37 | 1.74+ |
| TSW (g) | 11.99** | 2.28 | 1.07 | 16.52** | 1.80+ | 1.97* | 0.48 |
| T. to maturity (day) | 137.82** | 48.81** | 37.33** | 304.94** | 33.95** | 17.19** | 9.55** |
| Pl height(cm) | 0.37 | 114.19** | 4.16* | 13.43** | 5.98** | 0.43 | 2.12* |
| Nstra % | 11.71** | 13.42** | 9.83** | 5.41** | 6,75** | 4.61** | 1.69+ |
| Nsee % | 8.33** | 17.64** | 0.08 | 4.52** | 7.15** | 5.14** | 11.26** |
| Protein | 8.33** | 17.64** | 0.08 | 4.52** | 7.15** | 5.14** | 11.26** |
| Nstraw kg/ha) | 22.71** | 67.55** | 9.93** | 4.37** | 4.74** | 3.51** | 2.48** |
| Nseed (kg/ha) | 2.99 | 84.01** | 4.00+ | 10.97** | 6.48** | 5.06** | 7.32** |
| Nplant(kg/ha) | 21.95** | 134.67** | 0.97 | 6.15** | 4.22** | 3.61** | 2.75** |
| NUE | 11.60** | 13.71** | 4.51* | 4.38** | 5.35** | 2.13* | 1.41 |

**, *, +: Statistically significant difference at P=0.01, P=0.05, P=0.10; F-test in ANOVA. NUE=N use efficiency.

**Table 4.** Analysis of variance for yield; analysing all genotypes including *O. glaberrima* and analysing only *O. sativa* genotypes.

| Variance component | All genotype | | | | | Only *O. sativa* genotype | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Df | SS | MS | Var cp. | F | Df | SS | MS | Var cp. | F |
| Season (S) | 1 | 0.03 | 0.03 | $0^a$ | Ns | 1 | 1.94 | 1.94 | $0^a$ | Ns |
| Treatment (N) | 1 | 494.93 | 494.93 | 4.71 | ** | 1 | 532.40 | 532.40 | 5.52 | ** |
| NS | 1 | 95.22 | 95.22 | 1.80 | ** | 1 | 90.61 | 90.61 | 1.85 | ** |
| Genotype (G) | 12 | 197.43 | 16.45 | 0.94 | ** | 11 | 29.83 | 2.71 | 0.08 | * |
| GS | 12 | 55.51 | 4.62 | 0.41 | ** | 11 | 36.87 | 3.35 | 0.25 | ** |
| GN | 12 | 58.45 | 4.87 | 0.44 | ** | 11 | 21.30 | 1.93 | 0.07 | Ns |
| GNS | 12 | 15.44 | 1.28 | $0^a$ | Ns | 11 | 15.39 | 1.39 | 0.01 | Ns |
| RGN:S | 142 | 186.55 | 1.31 | 1.31 | | 130 | 174.01 | 1.33 | 1.33 | |

**, *, +: Statistically significant difference at P=0.01, P=0.05, P=0.10; F-test in ANOVA, $0^a$: negative estimate. NS = Nitrogen x Season interacton, GS = Genotyp x Season interaction, GN=Genotyp x Nitrogen interaction, GNS = Genotyp x Nitrogen x Season interaction

and interaction with the N level. For example, two genotypes Farox 304 and Farox 239 have very different yields at the low N-level (4,78 and 3,94 $t.ha^{-1}$, respectively), whereas at high N level, these two cultivars are the two highest yielding genotypes (8,09 and 8,49 $t.ha^{-1}$ respectively) (Figure 1). Figures 2 and 3 show relation between the total N-uptake and grain yield at low and high N level. Genetic variation in N-uptake occurs within *O. sativa* material. At low N-level, there is close relationship between N-uptake and grain yield (r= 0.79** without *O. glaberrima*). Highest N uptake and highest yield was realised by genotype Farox 304 (Figure 2). No relationship between N-uptake and grain yield was noted among *O. sativa* and *O. glaberrima* at high nitrogen input (r = 0.18 without Tog 6202) (Figure 3). Farox 239 obtained the best yield at high N-level with lower N-uptake compared to most other genotypes. Genotypes with higher N uptake do not have always the highest yield. Ratio of N in straw and N in seed at low and high input of all genotypes are summarized in Table 6.

Variability is observed among *O. sativa* genotypes. At low N level, varieties like IR31852, Sahel 202 and Farox 239 showed higher nitrogen content in straw with 0.50, 0.60 and 0.71, respectively. For N content in seeds at low N input, varieties IKP, Farox304, IR31851, Sahel 202 and 6202 Tog gave the best results with 0.60, 0.57, 0.56 and 0.82 respectively. Varieties IR31851 and Sahel 202 showed good ratio at low N level for N in straw as well as for N in seed. Other varieties with lower N ratio in straw and in seed at N0 like Jaya and ITA123, present better performance in N uptake at N150 (Figure 3). N efficiency and components of N efficiency at low and high N level

**Table 5.** Variance components for yield and yield components with all genotype (*O. sativa* + *O. glaberrima*) and without *O. glaberrima* genotypes.

| Traits | All genotypes | | | | Only *O sativa* genotypes | | | |
|---|---|---|---|---|---|---|---|---|
| | G | GS | GN | GNS | G | GS | GN | GNS |
| Tiller number | 142.35** | 264.76** | -18.007 | 24.48 | 123.53** | 58.48* | -25.41 | 34.99 |
| Panicle number | 108.27** | 203.55** | 7.13 | -13.65 | 102.69** | 50.02* | 10.60 | -10.38 |
| Panicle weight (g) | 1065** | 508.16** | 418.84* | -398.13 | 212.24* | 599.27** | 228.72+ | -345.41 |
| Yield (t/ha) | 0.94** | 0.41** | 0.44** | -0.006 | 0.08* | 0.25** | 0.07 | 0.01 |
| HI (%) | 22.45** | 1.94 | 9.20** | -2.41 | 7.41** | 0.21 | 10.31** | -1.12 |
| Straw (t/ha) | 1.44** | 0.88* | 0.36 | 1.46+ | 1.36** | 0.97* | 0.39 | 1.64+ |
| TSW (g) | 3.88** | 0.40+ | 0.48* | -0.52 | 4.23** | 0.40+ | 0.56* | -0.58 |
| TM (day) | 63.62** | 13.79** | 6.77** | 7.15** | 48.73** | 12.15** | 7.10** | 7.84** |
| Pl height (cm) | 27.31** | 21.89** | -2.49 | 9.80* | 2.9* | 9.99** | -2.24 | 1.87 |
| Nstraw % | 0.005** | 0.013** | 0.008** | 0.003+ | 0.005** | 0.014** | 0.009** | 0.004* |
| Nseed % | 0.005** | 0.0.19** | 0.013** | 0.065** | 0.006** | 0.011** | 0.014** | 0.07** |
| Protein | 0.21** | 0.76** | 0.51** | 2.54** | 0.24** | 0.44** | 0.54** | 2.73** |
| Nstr (kg/ha) | 119.36** | 264.92** | 178.22** | 210.19** | 113.46** | 268.70** | 196.92** | 211.09** |
| Nse (kg/ha) | 135.74** | 149.11** | 110.51** | 343.99** | 21.90** | 162.59** | 41.35** | 378.22** |
| Nplt (kg/ha) | 312.51** | 390.43** | 316.54** | 424.47** | 100.65** | 425.65** | 242.85** | 452.67** |
| NHI | 0.003** | 0.004** | 0.002** | 0.003* | 0.0015** | 0.0037** | 0.0013* | 0.0026* |
| NUE | 27.10** | 69.78** | 18.04** | 12.98 | 4.31 | 30.92** | 19.27* | 9.68 |

**, *, +: Statistically significant difference at P=0.01, P=0.05, P=0.10; F-test in ANOVA. Nstraw % = N concentration in straw , Nseed % = N concentration in seed, Nplt = Total N yield (N content in plant), Nstr = N straw yield (N content in straw) Nse = N seed yield (N content in seed).

are presented in Tables 7 and 8. According to Moll et al. (1982), N use efficiency (grain production per unit of N supply) can be divided into two components: efficiency of absorption (uptake efficiency) and efficiency with which N absorbed is utilised to produce grain. To calculate N uptake efficiency, we divided N content in plant (Nt) with N supply in the field (Ns). N utilisation efficiency was calculated by dividing grain yield (Gw) with Nt. For all genotypes, N use efficiency was lower at high N level than at low N level. Fertilisation had significant effect on N use efficiency and components of N efficiency. Differences in N efficiency and N efficiency components (uptake efficiency and utilisation efficiency) were noted at the two N levels. Variation in N uptake efficiency and N utilisation efficiency were also different at the two N-levels (Table 9). Without nitrogen, variations in uptake efficiency (78%) were higher than those in utilisation efficiency (22%). At 150 kg nitrogen per hectare, in contrary, variation in utilisation efficiency (73%) were more important as variation in uptake efficiency (27%).

## DISCUSSION

Many studies reported variation for yield and yield component at high and low N input (Tirol, 1996; Sahu ET al., 1997; Sinebo et al., 2004; Gallais and Hirel, 2004) as well as significant effect of Genotype (G) and N-fertilisation (Le Gouis et al., 2000; Gallais and Hirel, 2004; Chardon et al., 2010). Variance component GN (0.44) was nearly half as large as the genotypic variance (0.94). The interaction GN can be partly explained by the different reaction of the *O. glaberrima* genotype compared to *O. sativa*. Singh et al. (1998) made a similar observation in medium and long duration rice genotypes. The low recovery of the uptaken nutrient is the main factor limiting yield. Many studies in rice (Janssen, 1998; Singh et al., 1995) showed this low recovery aspect. Nitrogen uptake efficiency reflects the efficiency of the crop in obtaining N from the soil. Nitrogen utilization efficiency shows the efficiency with which N absorbed is utilised to produce grain. Nitrogen Use Efficiency is a combination of N uptake efficiency and N utilization efficiency. Increase of N uptake efficiency and/or N utilisation efficiency will lead to an increase of NUE. This could explain the best value of NUE under low nitrogen input. Autors like Raun and Johnson (1999) proposed increase N uptake efficiency as strategy to increase NUE. In various crops, N is accumulated during vegetative growth and remobilized after flowering and translocated to grain. During the grain filling stage, it is the N accumulated in leaf before flowering that is in large part remobilized to the grain and that contributes to grain N protein deposition (Mae, 1997). Moll et al. (1982) with eight maize hybrids and Kessel (2000) with oil seed rape species found similar variations in N use efficiency and components of N efficiency.

Moll et al. (1982) obtained 2.05, 46.88 and 95.7 as

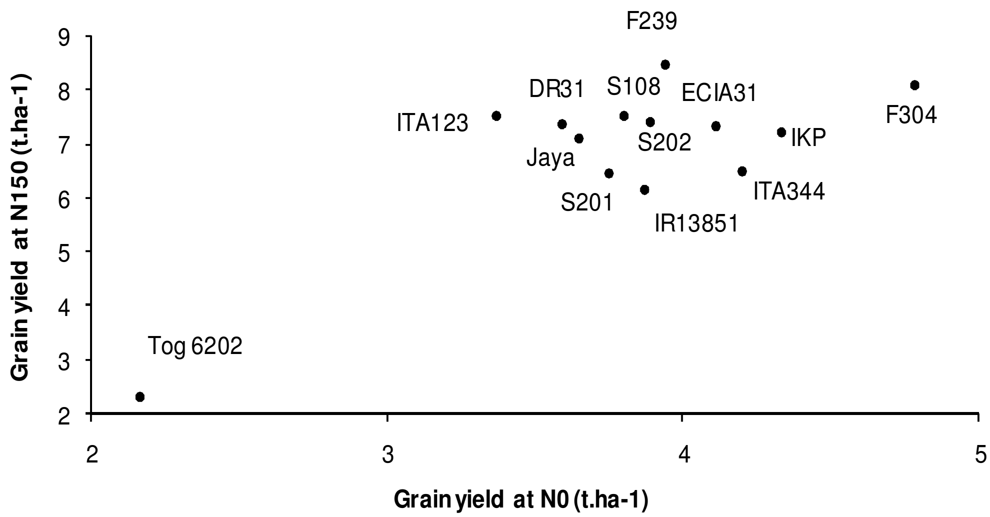


**Figure 1.** Grain yield at low and high nitrogen (N) input.

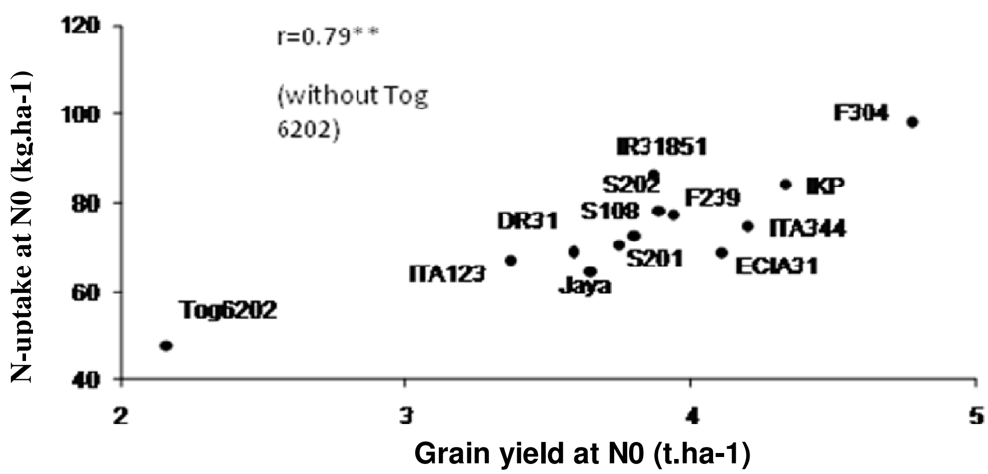


**Figure 2.** Total N-uptake and grain yield at N0.

uptake efficiency, utilisation efficiency and N use efficiency respectively at low N input, and 0.65, 41.4 and 26.5 as uptake efficiency, utilisation efficiency and N use efficiency at high N input. Similar results were obtained by many other crops. Working with oil seed rape species in many locations, Kessel (2000) found uptake efficiency higher than utilisation efficiency at low nitrogen supply and smaller at high nitrogen supply. That is in agreement with our results. In rice, genotypic variation in both nitrogen uptake and nitrogen use efficiency is in agreement with results of several studies for irrigated lowland conditions in Asia where total N content and nitrogen use efficiency were examined using a large number of cultivars (Inthapanya et al., 2000; Singh et al., 1998; Sahu et al., 1997). Those studies showed that genotypic variation in N content was significant under conditions of low soil fertility. Determining whether it is possible to select for genotypes that are adapted to low or high N fertilization or that perform well under both N fertilization conditions is a prerequisite to maintain high crop productivity under low N fertilization input. Despite yield reduction, a direct selection under low N fertilization input would be more effective than an indirect selection under high N fertilization input (Presterl et al., 2003). Working with accessions of *Arabidopsis thaliana* Chardon et al. (2010) demonstrated that NUE was exclusively genetically determined. According to Gallais and Coque (2005), when the plant material performs relatively well under low N input, it should be selected under N deficiency conditions for which yield reduction does not exceed 35 – 40%. QTLs for traits associated with physiological nitrogen use efficiency were identified.

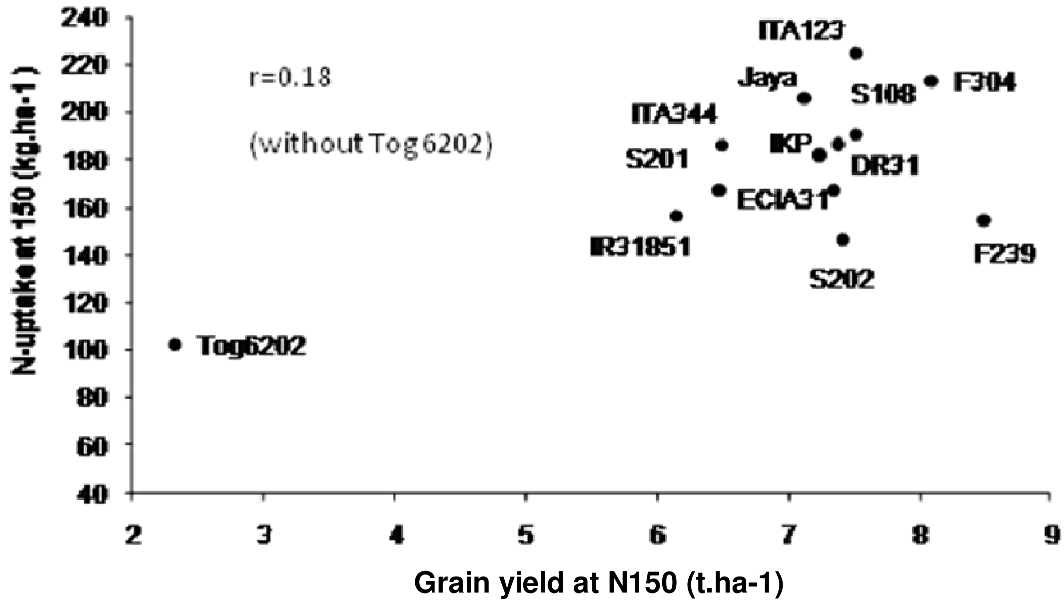


**Figure 3.** Total N-uptake and grain yield at N150.

**Table 6.** Ratio of Nstraw at N0: Nstraw at N150 and its comparison with Nseed at N0 : Nseed at N150.

| Genotypes | Nstraw (N0)/Nstraw (N150) | Nseed (N0)/Nseed(N150) |
|---|---|---|
| Sahel 108 | 0.34 | 0.42 |
| IKP | 0.34 | 0.60 |
| Farox 304-4-1-2 | 0.39 | 0.57 |
| IR 31851 | 0.54 | 0.56 |
| Jaya | 0.28 | 0.37 |
| ITA 344 | 0.41 | 0.39 |
| Sahel 201 | 0.39 | 0.45 |
| Sahel 202 | 0.60 | 0.50 |
| ITA 123 | 0.30 | 0.31 |
| ECIA31-6066 | 0.43 | 0.39 |
| DR 31 | 0.34 | 0.40 |
| Farox 239-3-3-2 | 0.71 | 0.38 |
| 6202 Tog | 0.34 | 0.82 |

Using recombinant inbred lines of rice, Young-Il Cho et al. (2007) found 20 single QTLs (S-QTLs) and 58 pairs of epistatic loci (E-QTLs) for the nitrogen concentration of grain, nitrogen concentration of straw, nitrogen content of shoot, harvest index, grain yield, straw yield and physiological nitrogen use efficiency in both conditions. Gallais and Hirdel (2004) studying genetic variability and genetic basis of nitrogen use efficiency in maize detected QTLs for traits of vegetative development, N-uptake and grain yield ant its components at high N level as well as at low N level. Good et al. (2007), compared wild-type canola and genetically modified canola where a barley AlaAT cDNA driven by a canola root specific promoter (btg26) was introduced in the genome. Transgenic plants had increased biomass and seed yield both in the laboratory and field under low N conditions, whereas no differences were observed under high N. Developing transgenic rice over expressing nodulin gene OsENOD93-1 linked to agronomical traits like shoot biomass and grain yield, Bi et al. (2009) demonstrate that transgenic approach can have a positive effect on nitrogen use efficiency. For the future, the efficiency of nitrogen inputs must be significantly improved. One key to optimising N use efficiency and minimising gaseous

**Table 7.** N use efficiency and components of N efficiency at N0.

| Genotypes | | Uptake | Utilisation | Uptake x Utilisation |
|---|---|---|---|---|
| | Yield (kg/ha) | Nt/Ns | Gw/Nt | Gw/Ns |
| Sahel 108 | 3800 | 0.72 | 52.53 | 38.00 |
| IKP | 4330 | 0.84 | 51.50 | *43.30* |
| IR 31851 | 3870 | 0.86 | 44.90 | 38.70 |
| Jaya | 3650 | 0.64 | 56.69 | 36.50 |
| ITA 344 | 4200 | 0.75 | 56.37 | *42.00* |
| Sahel 201 | 3750 | 0.70 | 53.43 | 37.50 |
| Sahel 202 | 3890 | 0.78 | 49.83 | 38.90 |
| ITA 123 | 3370 | 0.67 | 50.36 | 33.70 |
| ECIA 31-6066 | 4110 | 0.69 | 59.83 | *41.10* |
| DR 31 | 3590 | 0.69 | 52.22 | 35.90 |
| Farox 239-3-3-2 | 3940 | 0.77 | 51.01 | *39.40* |
| Means | | 0.74 | 52.60 | 38.64 |

**Table 8.** N use efficiency and components of N efficiency at N150.

| Genotype | | Uptake | Utilisation | Uptake x Utilisation |
|---|---|---|---|---|
| | Yield kg/ha | Nt/Ns | Gw/Nt | Gw/Ns |
| Sahel 108 | 7520 | 0.76 | 39.44 | 30.08 |
| IKP | 7240 | 0.73 | 39.76 | 28.96 |
| Farox 304 | 8090 | 0.85 | 37.95 | 32.36 |
| IR 31851 | 6150 | 0.63 | 39.28 | 24.60 |
| Jaya | 7120 | 0.83 | 34.44 | 28.48 |
| ITA 344 | 6500 | 0.74 | 34.93 | 26.00 |
| Sahel 201 | 6470 | 0.67 | 38.70 | 25.88 |
| Sahel 202 | 7420 | 0.59 | 50.38 | 29.68 |
| ITA 123 | 7520 | 0.90 | 33.35 | 30.08 |
| ECIA31-6066 | 7350 | 0.67 | 43.90 | 29.40 |
| DR 31 | 7380 | 0.75 | 39.56 | 29.52 |
| Farox 239-3-3-2 | 8490 | 0.62 | 54.91 | 33.96 |
| Means | | 0.73 | 40.55 | 29.08 |

Nt/Ns = Uptake efficiency; Gw/Nt = Utilisation efficiency; Gw/Ns = N use Effifciency.

**Table 9.** Relative contribution of variation in uptake and utilisation efficiency (% of total variance in N efficiency) in *O. sativa*.

| Efficiency | N0 | N150 |
|---|---|---|
| Uptake efficiency | 78 | 27 |
| Utilisation efficiency | 22 | 73 |

losses can be to avoid N inputs in excess of crop needs at any point during the growing season. Hence, the timing, rate, and method of fertiliser application have a large impact on efficiency. Several split applications of N are needed to achieve N supply that approximates plant demand. Application of marker assisted selection (MAS) in breeding for NUE (Agrama, 2006), widespread testing of recombined inbred line as well as breeding for genetically modified plant can also help to develop new N efficient varieties. According to Hirel et al. (2007), an approach that integrates genetic, physiological, and agronomic studies of the whole-plant N response will be essential to elucidate the regulation of NUE and to provide key target selection criteria for breeders and monitoring tools for farmers for conducting a reasoned fertilization protocol.

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