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Genotypic variation in Rice (*Oryza sativa* L.) for Nitrogen Use Efficiency Under Optimal and Sub Optimal Nitrogen Levels

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Abstract

A field experiment was conducted for two years (2011-12 and 2012-13) at the ICAR-Indian Institute of Rice Research (ICAR-IIRR) Rajendrangar, Hyderabad, to assess the differences in grain yield and nitrogen (N) utilization efficiency of rice genotypes. Fifteen popular high yielding genotypes with varying acquisition and utilization of soil and fertilizer N were tested at N-0 (no external application of N) and N-100 (100 kg N/ha) levels in each year covering four seasons (two wet and two dry seasons) in total. Significant differences among the genotypes were observed in grain yield and nitrogen use efficiency parameters such as: agronomic efficiency (AE), physiological efficiency (PE), recovery efficiency (RE), partial factor productivity of applied N (PFP), per day productivity (PDP), harvest index (HI), N requirement (NR), N uptake rate (NUR) and N harvest index (NHI). Based on the grain yield data, the genotypes were grouped into efficient, responsive and efficient as well as responsive genotypes. The N-efficient genotypes that produced high grain yield utilizing soil available N alone were: Swarna, Jaya, Sampada, DRRH2, Tulasi; the responsive genotypes to the applied N were: Rasi, Annada, Tulasi, IR 64; the efficient as well as responsive genotypes those gave higher yield both at N0 and N100 levels were: Varadhan, PHB 71, DRRH2, RPBio 4918-248, RPBio4919-458, KRH2, DRRH3, Akshayadhan. Based on the N use efficiency indices, the genotypes were ranked. Rasi, Tulasi, Annada, MTU 1010 and Anjali from early duration group; Varadhan, PHB 71, RP bio 4918-248, RPBio4919-458, KRH2 from medium duration group and Swarna from late maturing group were found most promising. Thus, genotypic variation for N use efficiency in rice was evident and in the present study, the performance of genotypes over a range of soil and fertilizer N supply was consistent over two seasons in some genotypes and with seasonal variation in some genotypes.

Key words: Genotypes, Grouping, Nitrogen levels, Nitrogen use efficiency, Ranking, Rice

Introduction

Rice is the most important staple food crop in Asia. More than 90% of the world's rice is grown and consumed in Asia, where 60% of the world's population lives. In India, rice crop occupies about 44 million hectares area with annual production of 104.32 million tonnes and productivity of 2239 kg/ ha (India stat 2012-13). Rice is the foremost intensively grown crop in India having high yielding capacity but with decreasing fertilizer use efficiency as one of the major constraints in rice soils. For almost three decades after the Green Revolution, the rice yield growth rate was approximately 2.5% per year, however, during 1990s, this has decreased to ≈ 1.0% (Riveros and Figures 2000) across the world.

Among all essential nutrients, nitrogen (N) is the major element which is required in large quantities by rice. The larger amount (95 to 99%) of N occurs in the organic forms as a part of the soil organic matter complex which is not immediately available to crop plants. It is only the inorganic form of NH4 -N and NO_3 –N which is commonly taken up by plants. At present, consumption of N fertilizer is in the increasing trend, but fertilizer use efficiency is low in most of the production systems. The most limiting nutrient in irrigated rice is nitrogen and N recovery efficiency is only about 25-40% of applied N in most farmers' fields and N is mostly lost by leaching, denitrification, gaseous loss through volatilization and surface run off. Hence, there is a need to achieve increased nitrogen use efficiency.

Nitrogen use efficiency not only depends on the efficient fertilizer management, but also on the cultivar that is used. Genotypes differ in their ability to absorb and utilize nutrients and these genotypic differences in efficiency are related to the acquisition by the roots or utilization by the plant or both (Marschner 1995) and genetic variation in nitrogen use efficiency in rice was reported by several workers (Ladha *et al*. 1998, Singh *et al*. 1998, Hiroshi 2003). The existing N use efficiency pattern and the factors responsible for N use efficiency in existing popular rice varieties need to be well understood for further improvement in N use efficiency. Hence, the present study was undertaken to evaluate the nitrogen use efficiency of existing popular rice varieties and to identify efficient genotypes based on N use efficiency indices.

Materials and Methods

Experimental site characteristics: A field experiment was conducted for two years (2011-2012 and 2012-2013), covering four crop seasons [two wet season (WS, *kharif*) and two dry season (DS, *rabi*)] on a deep black clayey vertisol (Typic pellustert), at the Indian Institute of Rice Research farm, Hyderabad (17˚19″ N latitude, 78˚23″ E longitude, 542 m altitude with mean annual precipitation of 750 mm), to assess the genotypic differences in nitrogen (N) use efficiency and to identify the efficient rice genotypes for their responsiveness and use of soil and applied N.. The experimental soil characteristics were: slightly alkaline (pH 8.1); non-saline (EC 0.7l dS/m); calcareous (free $CaCO_3$ 5.01%); with CEC 44.1 C mol (p+)/kg soil and medium soil organic carbon (0.70%) content. Soil available N was low (215 kg/ha); with high available phosphorus (46 kg P/ha), potassium (442 kg K/ha), and zinc (12.5 ppm).

Treatment details: Detailed field studies were conducted for two years during *kharif* and *rabi* seasons at two nitrogen levels [without any external N application (N0) and with a recommended level (100 kg N/ha, N100) of N application] as main treatments. For this, the field was divided into two separate blocks by making a deep trench of 4 feet between them and placing thick polythene sheets in the trench deep into the soil to avoid leaching from plot to plot. Fifteen (15) popular and high yielding genotype (varieties and hybrids) were tested as sub treatments in a split plot design with 3 replications. The same set of genotypes were tested in both *kharif* and *rabi* seasons. A total of 30 genotypes were evaluated in two years. The recommended dose of fertilizers were given at the rate of 100-40-40-10 kg N, P_2O_5, K_2O and Zn/ha during both seasons through urea, single super phosphate, muriate of potash and zinc sulphate, respectively. Nitrogen was given in three equal splits at basal, maximum tillering and panicle initiation stages (to N100 plot only) while P, K and Zn were given as basal doses only. Chemical plant protection measures, irrigation and weeding operations were done according to normal practice and uniformly for all the treatments.

Observations and data recorded: Grain and straw yields were recorded at harvest and grain and straw samples were analysed for N content using standard procedure by micro kjeldahl method. Nitrogen uptake by grain, straw and total (grain + straw) was calculated and different parameters of NUE indices (agronomic, physiological, recovery and internal efficiencies, per day productivity, N uptake rate per day, harvest index, internal efficiency, partial factor productivity etc.) were computed using grain yield and nitrogen uptake data. Based on the grain yield data at N0 and N100, the genotypes were grouped into efficient (E), responsive (R) and efficient and responsive (ER) genotypes as per Fageria and Baliger (1993). Based on their NUE indices, the genotypes were ranked based on their mean rank value for all indices as per the procedure followed by Singh *et al.* (1998). All the data were subjected to standard statistical analysis, by applying analysis of variance for split plot design. Least significant differences (LSD) were conducted at a 5% level of probability, where significance was indicated by F-test.

Results and Discussion

Grain yield at two levels of N application

In the first year (2011-12), during *kharif*, the grain yield was significantly higher at N 100 compared to N 0 which was higher by 42% (Table 1). With regard to genotypes, all genotypes were superior at N100 over N0. Among the genotypes, in the early group, Rasi out yielded (4.59 t/ha) the other varieties and Prasanna recorded the lowest yield (3.32 t/ha). In the medium duration group, Varadhan recorded maximum yield (6.01 t/ha) and Vasumati recorded the lowest yield (3.73t/ha). This group recorded higher yields than early and late duration varieties. Whereas, in the long duration group, Swarna recorded comparatively higher yield (4.58 t/ha) and BPT 5204 recorded lowest yield (4.22 t/ha).

Though interaction effects were non-significant, medium duration group varieties, Varadhan, Sampada and PHB 71 were superior to other varieties at N0 and other two groups (early and late) were at par. At N 100 also, Varadhan, PHB 71 and Jaya were superior to other varieties.

During *rabi* 2011-12, grain yield was significantly higher at N100 compared to N0 by 58% and the per cent yield reduction in N0 over N100 was higher in *rabi* compared to *kharif* showing the significance of N requirement in dry season (Table 1). With regard to genotypes, all genotypes were superior at N100 over N0. Among the early group, Prasanna recorded significantly lower yield than the other four varieties which were on par at N0 as well as N100. In general, in *rabi*, early varieties performed better with similar yield levels as in *kharif* compared to medium and long duration varieties that recorded lower yields than in *kharif* which could be attributed to the exposure to higher temperatures and water stress in the later stages of crop growth due to longer duration.

In the medium duration group, at N0, the aromatic rice varieties (Pusa Basmati 1 and Vasumati) recorded significantly lower yields compared to all other genotypes which were at par, while, at N100, the varieties, Varadhan, PHB71 and DRRH2 were on par and significantly superior to other varieties. In the long duration group, at N0, all three varieties were at par but at N100, Swarna and BPT5204 were significantly superior to Mahsuri.

Table 1: Grain yield (t/ha) of genotypes as influenced by treatments

***Kharif* 2011**					***Rabi* 2011-12**				
Genotypes	**N0**	**N 100**	**Mean**	**Diff.**	**Genotypes**	**N0**	**N 100**	**Mean**	**Diff.**
Rasi	3.28	5.90	4.59	2.62	Rasi	2.96	5.61	4.29	2.65
Anjali	3.76	4.30	4.03	0.54	Anjali	3.09	5.53	4.31	2.44
Annada	3.21	5.62	4.42	2.41	Annada	3.52	5.11	4.32	1.59
Prasanna	2.90	3.73	3.32	0.83	Prasanna	1.90	2.98	2.44	1.08
MTU 1010	3.68	5.18	4.43	1.50	MTU 1010	3.39	5.38	4.39	1.99
Varadhan	4.76	7.25	6.01	2.49	Varadhan	3.35	5.49	4.42	2.14
Jaya	3.87	6.23	5.05	2.36	Jaya	3.71	4.34	4.03	0.63
Sampada	4.52	5.52	5.02	1.00	Sampada	3.09	4.17	3.63	1.08
PHB 71	4.71	7.02	5.87	2.31	PHB 71	3.72	5.22	4.47	1.50
Pusa Basmati 1	3.65	4.86	4.26	1.21	Pusa Basmati 1	2.80	4.12	3.46	1.32
Vasumati	3.14	4.32	3.73	1.18	Vasumati	2.83	4.16	3.50	1.33
DRRH2	3.91	5.31	4.61	1.40	DRRH2	3.36	5.04	4.20	1.68
Swarna	3.93	5.23	4.58	1.30	Swarna	2.35	4.80	3.57	2.45
BPT 5204	3.31	5.12	4.22	1.81	BPT 5204	2.31	4.65	3.48	2.34
Mahsuri	3.45	4.79	4.12	1.34	Mahsuri	2.24	3.88	3.06	1.64
Mean	3.74	5.36			Mean	2.97	4.70	3.84	
CD(p=0.05)	Main – 1.31; Sub – 1.08; MxS - NS				CD(p=0.05)	M- 0.58; S-0.54; S at M-0.76; M at S – 0.78			

In the second year (2012-13), during *kharif* 2012, all the genotypes recorded significantly higher grain yields at N100 over N0 similar to first year and the mean % yield reduction in N0 over N100 was 39% (Table 2). At N0, the genotypes RPbio4919-377/13, RPbio4919-458, KRH2, DRRH3, Akshayadhan and Swarna performed well recording 4.06-4.35 t/ha which were significantly superior to other varieties. At N100 level also, these genotypes were significantly superior with a grain yield range of 5.0-6.46 t/ha. Tulasi (3.75 t/ha) in early, KRH2 (4.25 t/ha) in medium and Swarna (4.06 t/ha) in the long duration group were superior to other varieties in their group at N0. Whereas, at N100, RPBio 4919-458 (6.46 t/ha) in medium and Swarna (5.07 t/ha) in the long duration group were high yielders. Best performance of high yielding rice cultivars even at reduced N fertilizer rate was reported by Hiroshi (2003).

Similar to the *kharif* 2012, during *rabi* 2012-13 also, grain yield was significantly higher at N 100 (5.26 t/ha) compared to N 0 (3.13 t/ha) which was higher by 68%. Compared to *kharif*, the per cent yield increase to N application was higher in *rabi* in both years showing the significance of N response in dry season. Much higher absolute grain yield and N response in dry season than in wet season in the tropics was also reported by De Datta and Malabuyoc (1976). With regard to genotypes, all genotypes were superior at N100 over N0 in their grain yield. This could be attributed to the fact that higher nitrogen application might have increased the chlorophyll formation and improved photosynthesis and thereby increased the plant height, number of leaves and number of tillers per unit area leading to the production of high dry matter resulting in higher yield (Tejeswara *et al.* 2014).

Table 2: Grain yield (t/ha) of genotypes as influenced by treatments

Kharif 2012					*Rabi* 2012-13				
Genotypes	**N0**	**N 100**	**Mean**	**Diff.**	**Genotypes**	**N0**	**N 100**	**Mean**	**Diff.**
Rasi	3.13	4.85	3.99	1.72	Rasi	2.94	5.11	4.03	2.17
Aditya	2.94	4.44	3.69	1.50	Aditya	2.88	5.04	3.96	2.16
Tulasi	3.75	4.8	4.28	1.05	Tulasi	2.87	5.82	4.35	2.95
Tellahamsa	3.3	3.94	3.62	0.64	Tellahamsa	2.83	5.06	3.95	2.23
Krishnahamsa	3.52	4.81	4.17	1.29	Krishnahamsa	2.54	4.75	3.65	2.21
IR 64	3.44	4.74	4.09	1.30	IR 64	2.62	5.42	4.02	2.80
KRH 2	4.25	5.74	5.00	1.49	KRH 2	3.17	5.96	4.57	2.79
DRRH3	4.12	5.45	4.79	1.33	DRRH3	3.27	5.48	4.38	2.21
RPBio 4918-248	3.97	6.12	5.05	2.15	RPBio 4918-248	3.48	6.03	4.76	2.55
RPBio 4919-458	4.13	6.46	5.30	2.33	RPBio 4919-458	3.49	5.74	4.62	2.25
RPBio 4919-377-13	4.35	5.65	5.00	1.30	RPBio 4919-377-13	3.85	5.3	4.58	1.45
Akshayadhan	4.17	5.56	4.87	1.39	Akshayadhan	3.49	5.88	4.69	2.39
Swarna	4.06	5.07	4.57	1.01	Swarna	4.1	5.14	4.62	1.04
RPBio 226	2.72	4.25	3.49	1.53	RPBio 226	2.75	3.84	3.30	1.09
Sugandhamati	3.18	4.64	3.91	1.46	Sugandhamati	2.73	4.67	3.70	1.94
Mean	3.67	5.1		28.2	Mean	3.13	5.26		
CD(p=0.05)	M-0.40; S-0.33MxS-0.47; SxM-0.49				CD(p=0.05)	M- 0.70; S-0.43; MxS-0.68; SxM-0.61			

In the early group, all four genotypes (Rasi, Aditya, Tulasi,Tellahamsa) were on par at N0 and at N 100, Tulasi was superior to other genotypes. All genotypes were responsive to applied N and the response was the highest in Tulasi. In the medium duration group, RPbio 4918-248, RPbio 4919-458, Akshayadhan and KRH2 were found to be more efficient in soil N utilization and also responsive to applied N. Most of the genotypes in this medium group recorded higher yields than early and late duration entries both at N0 and N100 levels. In the long duration group, Swarna was significantly superior to other two varieties with its consistent performance (by 20-35% higher yield) in both seasons. The variation in grain yield among different varieties was due to the differential efficiency of these varieties in converting dry matter into grain. Similar findings were also reported regarding varietal performance under different nitrogen levels in rice by Priydarshini and Prasad (2003) and Srilaxmi *et al*. (2005). Kanade and Kalra (1986) also reported highest paddy yield in highest nitrogen application.

Genotypic variation in nitrogen use efficiency (NUE) indices

NUE indices of the genotypes tested in two years are given in tables 3-6. In general, the agronomic efficiency (AE), physiological efficiency (PE), internal efficiency (IE), recovery efficiency (RE) and partial factor productivity (PFP) are higher in the genotypes that recorded higher grain yield either at N0 or at N100 levels and these values are close/similar to the optimum recommended values as suggested by Dobermann and Fairhurst (2000). According to them, optimum AE, PE, IE, RE and PFP values are 10 to 30, 40 to 60, 55 to 65, 30 to 50, and 40 to 80, respectively. The trend was similar in both the years and most of these NUE indices are higher in medium duration varieties followed by early duration varieties. Hiroshi (2003), from his experiments, also opined that medium maturity high yielding rice cultivars with higher NUE are appropriate for N reduced input systems.

If we see the seasonal variation, AE, PE, IE and HI values were higher in dry season which could be attributed to better sunshine in dry season that might have helped for efficient utilization of the absorbed nitrogen and comparatively higher grain yield than straw yield in dry season, while, RE, PFP and PDP were higher in wet season. The higher per day productivity could be due to early maturity in wet season compared to dry season where crop will be subjected to very low temperatures in the early crop stages and actual duration will be more in dry season. In both the years, N required for the production of one tonne grain was marginally lower in dry season compared to wet season there by indicating better utilization efficiency of N in dry season. Whereas, in case of NHI, that is, partitioning of N to grain, genotypic variation was evident though not much seasonal variation was observed. NHI also reflects the grain protein content and thus the grain nutritional quality (Sinclair 1998). Genetic variation in NUE of irrigated rice in Senegal was also reported by Gueye and Becker (2011).

Table 3: Important nitrogen use efficiency (NUE) indices of genotypes (*kharif* 2011)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	26.2	37	70	59	15	20.3	33	59	66	49	0.52	0.51	0.65	0.67
Anjali	5.4	15	36	43	12.2	19.0	36	41	82	53	0.53	0.50	0.76	0.73
Annada	24.1	36	67	56	13.7	19.8	29	51	73	50	0.50	0.50	0.66	0.61
Prasanna	8.3	19	43	37	15	23.3	31	39	67	43	0.50	0.42	0.66	0.65
MTU 1010	15	25	61	52	13.8	21.6	32	45	72	46	0.53	0.45	0.70	0.59
Varadhan	24.9	44	57	72	13.5	16.7	37	56	74	60	0.53	0.53	0.66	0.72
Jaya	23.6	46	51	62	13.4	16.6	30	48	74	60	0.52	0.49	0.72	0.68
Sampada	10	31	32	55	13.5	16.8	33	41	74	59	0.51	0.47	0.70	0.66
PHB 71	23.1	28	83	70	12.5	20.3	35	52	80	49	0.54	0.46	0.69	068
PusaBasmati 1	12.1	24	50	49	14.3	20.9	28	37	70	48	0.52	0.44	0.72	065
Vasumati	11.8	22	54	43	18.9	26.3	24	33	53	38	0.42	0.38	0.61	0.51
DRRH 2	14	26	54	53	13.1	19.8	30	41	76	50	0.52	0.53	0.59	0.68
Swarna	13	18	71	52	16.7	26.1	28	37	60	38	0.50	0.39	0.47	0.50
BPT 5204	18.1	29	61	51	16.5	22.7	24	37	60	44	0.45	0.38	0.63	0.61
Mahsuri	7.5	18	42	48	18.8	24.6	29	34	53	41	0.39	0.35	0.61	0.54
CD (p=0.05)	1.25	0.43	0.43	2.24	1.98	0.64	1.73	1.50	3.96	0.75	0.071	0.071	0.071	0.071

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 4: Important nitrogen use efficiency (NUE) indices of genotypes (*Rabi* 2011-12)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	29.2	69	42	59	10.9	12.7	22	41	91	79	0.59	0.60	0.74	0.74
Anjali	24.4	52	47	55	12.6	15.5	23	41	79	65	0.54	0.53	0.65	0.65
Annada	15.9	52	30	51	11.3	13.7	26	38	88	73	0.58	0.55	0.72	0.70
Prasanna	9.8	52	19	27	14.0	15.9	15	23	71	63	0.53	0.45	0.69	0.66
MTU 1010	19.9	65	30	54	13.0	13.9	25	40	77	72	0.57	0.56	0.69	0.71
Varadhan	21.4	46	46	55	12.0	15.7	25	40	83	64	0.58	0.52	0.74	0.74
Jaya	6.3	31	20	43	11.9	14.8	27	31	84	67	0.59	0.54	0.66	0.65
Sampada	10.8	56	19	42	13.5	14.6	21	28	74	68	0.51	0.51	0.62	0.64
PHB71	15.0	62	24	52	11.3	12.7	27	38	88	79	0.60	0.58	0.75	0.72
PusaBasmati 1	13.2	44	30	41	13.4	16.4	20	30	75	61	0.50	0.49	0.63	0.64
Vasumati	13.3	64	21	42	15.8	15.7	21	30	63	64	0.49	0.51	0.63	0.66
DRRH2	16.8	56	30	48	11.8	14.0	24	36	88	74	0.59	0.54	0.73	0.70
Swarna	22.9	65	35	46	14.8	15.1	14	28	67	66	0.42	0.47	0.58	0.59
BPT 5204	24.9	65	29	48	18.0	15.0	14	29	55	67	0.43	0.46	0.55	0.60
Mahsuri	16.4	62	26	39	17.0	16.6	14	24	59	60	0.36	0.42	0.48	0.57
CD(p=0.05)	4.3	2.8	2.4	5.8	1.50	1.82	1.98	0.75	1.9	5.1	0.064	0.035	0.069	0.069

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 5: Important nitrogen use efficiency (NUE) indices of genotypes (*Kharif* 2012)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	17	39	45	49	18.1	21.1	26.3	40.8	55	48	0.47	0.53	0.60	0.65
Aditya	15	42	38	44	18.0	20.4	24.6	37.3	56	49	0.53	0.53	0.61	0.63
Tulasi	11	26	38	48	14.9	19.6	31.4	40.3	67	51	0.59	0.53	0.64	0.61
Tellahamsa	7	31	24	40	17.3	20.3	27.5	33.4	58	50	0.46	0.44	0.56	0.65
Krishnahamsa	13	31	41	48	15.4	19.8	28.2	38.5	65	51	0.49	0.44	0.60	0.59
IR 64	13	59	26	47	16.9	17.0	27.5	37.9	59	57	0.48	0.48	0.62	0.62
KRH 2	15	35	44	57	12.8	17.2	32.4	43.8	79	59	0.52	0.46	0.65	0.57
DRRH3	13	21	75	55	12.5	23.2	31.5	41.6	80	45	0.52	0.43	0.70	0.54
RPBio 4918-248	21	47	47	61	13.6	16.5	29.4	45.3	74	61	0.48	0.43	0.66	0.61
RPBio 4919-458	23	55	43	65	12.7	14.7	30.6	47.9	79	68	0.46	0.44	0.61	0.72
RPBio 4919-377-13	13	36	37	56	12.2	15.9	32.2	41.9	83	63	0.46	0.46	0.71	0.64
Akshayadhan	13	33	40	56	14.6	18.4	30.9	41.2	69	55	0.44	0.46	0.61	0.67
Swarna	10	41	34	51	14.7	18.5	27.1	33.8	69	55	0.44	0.43	0.62	0.57
RPBio 226	15	47	40	43	17.3	20.5	20.1	31.5	58	51	0.38	0.43	0.58	0.63
Sugandhamati	15	47	32	46	17.1	18.6	22.7	33.1	59	54	0.41	0.40	0.63	0.61
CD(p=0.05)	1.5	3.1	2.7	2.8	2.04	0.87	1.31	3.22	3.8	2.8	0.08	0.063	0.043	0.076

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 6: Important nitrogen use efficiency (NUE) indices of genotypes (*Rabi* 2012-13)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	21.7	75.9	28.6	51.1	16.5	15.1	24.7	42.9	60.7	66.3	0.55	0.54	0.72	0.67
Aditya	21.7	80.7	26.9	50.4	16.8	14.9	24.2	42.4	59.4	67.0	0.56	0.53	0.75	0.70
Tulasi	29.4	49.8	59.2	58.2	13.3	16.7	24.1	48.9	75.4	59.8	0.57	0.56	0.70	0.69
Tellahamsa	22.6	44.8	50.6	51.0	14.2	17.8	23.6	42.5	70.5	56.2	0.55	0.51	0.69	0.74
Krishnahamsa	22.1	49.3	44.9	47.5	12.7	16.3	20.3	38.0	78.2	61.5	0.53	0.49	0.66	0.64
IR 64	28.0	65.9	42.5	54.2	16.3	15.7	20.9	43.3	61.2	63.6	0.44	0.54	0.58	0.62
KRH 2	28.9	59.2	48.8	59.6	15.7	21.1	20.2	28.2	80.4	68.5	0.56	0.55	0.69	0.65
DRRH3	22.2	57.0	38.9	54.8	12.4	14.6	23.4	45.5	69.3	63.7	0.52	0.48	0.60	0.57
RPBio 4918-248	25.5	61.0	41.8	60.3	14.4	15.7	24.9	41.9	78.3	69.9	0.53	0.46	0.63	0.63
RPBio 4919-458	22.6	42.1	53.6	57.4	13.6	18.7	19.5	33.4	81.9	59.7	0.52	0.49	0.68	0.55
RPBio 4919-377-13	14.5	38.3	37.8	53.0	12.8	14.3	25.8	44.7	76.8	60.3	0.54	0.51	0.68	0.60
Akshayadhan	23.9	59.6	40.1	58.8	12.2	16.7	25.8	42.5	72.0	66.4	0.52	0.50	0.61	0.61
Swarna	10.4	40.8	25.6	51.4	13.0	16.6	28.5	32.0	74.2	63.6	0.55	0.51	0.72	0.63
RPBio 226	10.9	28.6	38.0	38.4	13.9	15.1	25.8	43.5	63.8	47.3	0.46	0.40	0.66	0.55
Sugandhamati	19.4	38.6	50.3	46.7	13.5	15.7	27.3	34.3	73.6	53.5	0.52	0.47	0.72	0.52
CD(p=0.05)	1.5	6.0	3.0	2.3	0.99	1.36	1.52	1.46	3.2	4.1	0.069	0.095	0.064	0.059

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Grouping of genotypes based on grain yield

Based on the grain yield recorded at N0 and N100, the genotypes were grouped in to efficient (E), responsive (R), efficient and responsive (ER) and Non efficient and non-responsive (NE,NR) as per Fageria and Baliger (1993). The first group was efficient (E), Where these genotypes produced more than average yield of 15 genotypes at N0 (low N) level, but response to N application at (N 100) was lower than the average yield. The genotypes Swarna and DRRH2 in *kharif* 2011; Jaya and Sampada in *rabi* 2011-12; Tulasi and Swarna in *kharif* 2012 and Swarna in *rabi* 2012-13 are falling in this group (Table 7). The second group was responsive (R) group and here the genotypes which produced less than average grain yield of 15 genotypes at N0 level, but responded to N application (N100) that is, recorded more than the average yield are classified in this group. The genotypes falling into this group were: Rasi and Annada in *kharif* 2011; Rasi and Swarna in *rabi* 2011-12 and Tulasi, Rasi, IR64 and Aditya in *rabi* 2012-13. The third group of genotypes can be considered as efficient and responsive (ER). The genotypes which produced above the average yield of 15 genotypes both at N0 and N100 levels were classified into this group. Genotypes Varadhan, Jaya, Sampada and PHB 71 in *kharif* 2011; Anjali, Annada, MTU1010, Varadhan, PHB71 and DRRH2 in *rabi* 2011-12; KRH2, DRRH3, Akahayadhan, RP bio4919/377-13, RP bio 4918-248 and RPbio 4919-458 in both seasons of *kharif* 2012 and *rabi* 2012-13 fall into this group.

The genotypes which fall into ER group are most desirable because these genotypes can produce more at a low N level and also respond well to the applied N and they can perform better under wide range of N environments. The next desirable group is efficient (E) because genotypes of this group perform well under low N level producing more than average yield and these can directly go to the resource poor farmers. The responsive (R) genotypes can be used in breeding programs. The rest of the genotypes fall into fourth group, non efficient and non responsive (NE, NR) and these are less desirable from NUE point of view. Similar results were reported by Fageria and Filho (2001) in low land rice genotypes.

Table 7: Grouping of genotypes based on grain yield

Group	*kharif* 2011	*rabi* 2011-12	*kharif* 2012	*rabi* 2012-13
Efficient (E)	Swarna, DRRH2	Jaya, Sampada	Tulasi, Swarna	Swarna
Responsive (R)	Rasi, Annada	Rasi, Swarna	-	Rasi, Tulasi, IR64, Aditya
Efficient and responsive (E,R)	Varadhan, Jaya, Sampada, PHB 71	Anjali, Annada, MTU1010, Varadhan, PHB 71, DRRH2	RPBio4918-248, RPBio4919-458, KRH2, DRRH3, Akshayadhan, RPbio4919/377-13	RPBio4918-248, RPBio4919-458 Akshayadhan, RPBio 4919-377-13, KRH2, DRRH3

Ranking of genotypes based on nitrogen use efficiency (NUE) indices

Based on the NUE indices, the genotypes were ranked. Since none of the genotypes possessed same rank for all NUE indices and no single genotype recorded all maximum values, the ranking was done based on the mean value of their ranks (Table 8) as was also reported by Singh *et al.* (1998) and Rao *et al.* (2006). Thus, Varadhan and MTU 1010 in *kharif* and *rabi* of 2011- 12 and KRH2 in both seasons of 2012-13 topped the list with lowest mean rank values. Similarly, in the duration wise ranking (Table 9), Rasi, Annada, MTU1010, Anjali and Tulasi in the early; Varadhan, PHB71, KRH2, RP bio 4918-248 in the medium and Swarna in the late maturity group were found most promising genotypes with almost similar response in both seasons. The genotypes, Rasi and Swarna showed their consistent superiority in two consecutive years. The consistent performance of efficient genotypes over a range of soil and fertilizer N supply was also reported by Singh *et al.* (1998). A close observation of grouping and ranking of genotypes based on grain yield and NUE indices indicated the emergence of same set of genotypes from both categories as the most N use efficient genotypes. Similar ranking system and genotype performance for NUE in rice was also given by Broadbent *et al.* (1987).

Table 8: Ranking of genotypes based on NUE indices

kharif 2011			*rabi* 2011-12			*kharif* 2012			*rabi* 2012-13		
Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank
Varadhan	4.4	1	MTU 1010	4.5	1	KRH2	5.6	1	KRH2	4.5	1
PHB 71	4.9	2	Varadhan	4.9	2	RPBio4918-248	5.7	2	RPBio4918-248	5.6	2
Rasi	5.1	3	Anjali	5.7	3	RPBio4919-458	5.7	3	Tulasi	6.1	3
Jaya	5.9	4	Rasi	6.2	4	Rasi	5.8	4	Akshayadhan	7.5	4
Annada	6.6	5	PHB71	6.2	5	Akshayadhan	5.9	5	Rasi	7.6	5
MTU 1010	7.3	6	Annada	6.4	6	DRRH3	6.8	6	RPBio4919-458	7.6	6
DRRH2	7.4	7	DRRH 2	7.3	7	RPBio4919-377-13	6.9	7	Aditya	7.8	7
Sampada	7.6	8	Vasumati	8.1	8	Tulasi	7.4	8	Krishnahamsa	7.9	8
Anjali	7.7	9	Swarna	8.5	9	Krishnahamsa	8.0	9	Swarna	7.9	9
PusaBasmati 1	8.5	10	Jaya	8.8	10	Aditya	8.1	10	Tellahmamsa	8.8	10
Swarna	9.5	11	Sampada	9.4	11	IR64	8.2	11	IR64	8.9	11
Prasanna	9.8	12	BPT 5204	9.9	12	Swarna	8.6	12	RPBio4919-377-13	9.0	12
BPT 5204	10.0	13	PusaBasmati 1	9.9	13	Tellahmamsa	9.3	13	DRRH3	9.1	13
Vasumati	11.1	14	Mahsuri	11.4	14	Sugandhamati	9.6	14	Sugandhamati	10.2	14
Mahsuri	11.6	15	Prasanna	12.8	15	RPBio226	9.7	15	RPBio226	12.0	15

Table 9: Ranking of genotypes duration wise (days)

Early (110-120)	Medium (125-135)	Late (>140)	Early	Medium	Late
***kharif* 2011**			***kharif* 2012**		
Rasi	Varadhan	Swarna	Rasi	KRH2	Swarna
Annada	PHB71		Tulasi	RPbio 4918-248	
MTU 1010	Jaya		Aditya	RPbio 4919-458	
rabi 2011-12			*rabi* 2012-13		
MTU 1010	Varadhan	Swarna	Tulasi	KRH2	Swarna
Anjali	PHB71		Rasi	RPbio 4918-248	
Rasi	DRRH 2		Aditya	Akshayadhan	

From the present study, it can be concluded that significant genotypic variation was observed with regard to grain yield and various nitrogen use efficiency (NUE) indices under sub-optimal as well as optimal N conditions. Significant seasonal variation from the data indicated higher response to N application in dry season compared to wet season with regard to grain yield and most of the NUE indices. Among the different duration groups, medium duration genotypes were superior to early and late maturing groups in terms of their efficiency in utilizing soil available N as well as applied N. The seasonal variation in response to N and N use efficiency of the genotypes was evident in case of some genotypes. Based on the grain yield and N use efficiency indices, Rasi, MTU 1010, Tulasi and Aditya from early; Varadhan, PHB 71, RPBio 4918-248 and KRH2 from medium; Swarna from late maturing groups were found most promising and are the most desirable genotypes for a wide range of soil N availability.

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