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Response of seed yield and nitrogen use efficiencies of rice cultivars as affected by N fertilizer rates

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Abstract

In order to study the effect of N fertilizer rates on yield and yield components of rice cultivars, a study was carried out in Rice Research Institute of Rasht, Iran in 2008. It was a two-variable factorial experiment based on a randomized complete block design with three replications. The main plot was N fertilization at four rates of 0, 30, 60 and 90 kg/ha and the sub-plot was rice cultivar at three levels of Hashemi, Ali-Kazemi and Khazar. The results of analysis of variance showed that the change in applied N rate significantly affected seed yield, N accumulated in plant and seed and N recovery and physiological efficiencies. Also, the effect of cultivar was significant on seed yield, N accumulated in plant and seed and N agronomical and physiological efficiencies, but the interaction between N and cultivar did not significantly affect any studied traits. Means comparison showed that as N rate was increased from 0 to 90 kg/ha, seed yield and N accumulated in seed increased by 84.5 and 65%, respectively; but as it was increased from 30 to 90 kg/ha, N recovery efficiency decreased by 33.8% and N physiological efficiency increased by 40%. Cultivar Khazar with the average seed yield of 3424.51 kg/ha, N agronomical efficiency of 24.43 kg/kg, N recovery efficiency of 42.11% and N physiological efficiency of 58.97 kg/kg had the highest potential of using applied N among the studied cultivars. In total, the results indicated that cv. Khazar was better to be cultivated accompanied with the application of 90 kg N/ha in order for having the maximum production and minimum lose of applied N under the conditions of the current study.

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Introduction

Rice is a major food crop in South America, Asia, and Africa (Fageria *et al.*, 2009) and soil fertility is the underpinning of yield escalation, and N is the most limiting nutrient in rice yield (Peng, 2000). Also, determining N use efficiency (NUE) in yield is an important technique for specifying the fate of chemical fertilizers application and their role in improving the yield.

In a study in Australia, rice seed yield increased with the increase in N rate, so that it increased by about 1.8 t/ha per 70 kg N/ha. The increase in N rate increased its uptake by roots, too (DeData, 1986). In a study on the effect of cultivar and N management on yield and NUE of rice, Ohnishi *et al.* (1999) showed that N uptake rate at spike meristem formation stage had a significant, non-linear (quadratic) relation with yield (r^2 = 0.864), dry weight (r^2 = 0.935) and leaf area index (r^2 = 0.969) in this stage. A similar relation between absorbed N and these variables were observed at spike emergence and maturity stages, too. In a study on the effect of N on seed NUE of dwarf and normal cultivars of rice in Mediterranean climate, Koutroubasa and Ntanos (2003) reported that NUE of dwarf cultivars was significantly higher as comprised with normal cultivars and NUE of late-maturity cultivars was significantly higher as comprised with early- and mid-maturity cultivars. They stated that nitrogen physiological efficiency depended on N harvest index and the ratio of seed yield to absorbed N rate by seeds and that the share of absorbed N by seeds in increasing nitrogen physiological efficiency was higher than that of N harvest index.

Some researchers reported that the N recovery efficiency (kg absorbed N by plant/kg applied N) was 30-50% in research fields and N agronomical efficiency per each kg applied fertilizer was about 15-25 kg which varied with growth season, yield and fertilization timing and rate (Yoshida, 1981). According to the results of De Data *et al.* (1988) and Schnier *et al.* (1990), the NUE of rice fields have rarely been more than 30-40%. Even the application of the best farming operations can rarely increase it to 60-65%. Also, Cassman *et al.* (1993) reported that only 30-40% of applied N by farmers can increase N accumulation in aerial parts of the plant.

Patial *et al.* (2001) evaluated the effect of the application of 40, 80 and 120 kg N/ha at two phases (base fertilizer and 3-5 days before the formation of spike meristem and spike emergence) on rice in three years and indicated that N recovery, agronomical and physiological efficiencies were significantly affected by N rate at 1% level, so that N recovery efficiency decreased with the increase in N rate.

In study on the effect of application of 0, 150, 225 and 300 kg N/ha on four rice genotypes on two types of soil (sandy and clay), Quanbao *et al.* (2007) showed that N application increased seed yield by 72.5-130.1% on sandy soil and 64.6-104.4% on clay soil and that different genotypes had different responses to N fertilization. The results showed that all NUEs were significantly affected by applied N rate, so that N harvest index of all genotypes significantly decreased as applied N rate was increased. Moreover, the application of N on sandy soil increased N recovery efficiency while on clay soil, the increase in N rate up to 225 kg/ha increased N recovery efficiency and further increase significantly decreased it. As N fertilization rate was increased, N agronomical and physiological efficiencies of all genotypes on both soils significantly decreased but N accumulated in plant and seeds increased.

Haefele *et al.* (2008) studied the effect of application N on 19 rice genotypes and concluded that seed yield and N accumulated in plant were significantly affected by applied N rate and genotype but N recovery efficiency was only affected by genotype. However, in a study on the effects of 40, 60 and 80 kg N/ha, Sikdar *et al.* (2008) reported that the change in applied N rate had no significant effect on N accumulated in seeds.

Gafariani *et al.* (2010) evaluated the N efficiency of grain sorghum genotypes and find that no-N application treatment had the highest N agronomical, recovery and physiological efficiencies, so that its physiological efficiency was 15.2 and 43% higher as comprised with N rates of 46 and 92 kg/ha and its agronomic efficiency was 40.2 and 107.7% higher than that of N rates of 46 and 92 kg/ha, respectively and that N recovery efficiency decreased from 82.34 to 57.56% as N rate was increased from 0 to 92 kg/ha. However, N fertilization rate of 46 kg/ha had the highest grain yield which was 18.9% higher than that of no-fertilization treatment and was ranked in the same statistical group with N fertilization rate of 92 kg/ha.

The objective of the current study was to evaluate the effect of different N fertilization rates on seed yield and N efficiency of different rice genotypes.

Materials and methods

The study was carried out in research field (Lat. 37°16´ N., Long. 41°37´ E., Alt. -7 m.) of Rice Research Institute of Rasht, Iran in 2008. Rasht in province of Gilan has a unique climate in Iran which is similar to Mediterranean climate. Its annual precipitation on the basis of average decade precipitation was 1330 mm.

Soil analysis showed that its pH was 7.4 and its total N percentage was 0.19 with the texture of silty-clayey. The study was a two-variable factorial on the basis of a randomized complete block design with three replications. The main plot was N fertilization at four rates of 0, 30, 60 and 90 kg/ha and the sub-plot was cultivar including Hashemi, Ali-Kazemi and Khazar. The plots were 3×5 m^2 and they were separated by borders.

The seeds were sown in a nursery in mid-April and the plots were fertilized by intended N fertilization rates as well as 100 kg P_2O_2 and K_2O/ha before transplanting. The fertilizer sources included urea, triple super phosphate and potassium sulfate. The transplanting was carried out in mid-May during which three transplants were planted on each pile of plots. The spacing between transplants was 20×25 cm^2. The plots were conventionally irrigated up to 10 days before harvesting. To prevent fertilizer exchange of treatments, all borderlines of plots were covered by plastic down to the depth of 30 cm.

To determine seed yield, three rows were eliminated from the margins and all the remaining plants were thoroughly cut. After winnowing and separating the seeds from panicles, they were dried in an oven at the temperature of 75°C for 48 hours and then, they were weighed and seed yield per area unit was calculated on the basis of 14% moisture.

N agronomical efficiency (amount of excessive yield compared with no-fertilization treatment per each kg applied N), N recovery efficiency (amount of recovered and absorbed N by plants per total applied N), N physiological efficiency (amount of excessive yield for each kg excessive absorbed N) and N harvest index (the ratio of absorbed N by seed to the absorbed N by whole plant at maturity stage) were calculated by the following equations:

$$AE_N = \frac{GY_N - GY_0}{F_N}$$

$$PE_N = \frac{GY_N - GY_0}{UN_N - UN_0}$$

$$RE_N = \frac{UN_{+N} - UN_{+N}}{FN}$$

$$NHI = \frac{UN_{seed}}{UN_{biomass}} \times 100$$

where, AE_N is N use agronomical efficiency, PE_N is N use physiological efficiency, RE_N is N recovery efficiency and NHI is N harvest index. In addition, GY_N is seed yield of fertilized treatment, GY_o is seed yield of no-fertilized treatment, UN_N is absorbed N of fertilized treatment, UN_o is absorbed N in no-fertilized treatment, F_N is applied N, UN_{seed} is absorbed N by seeds and $UN_{biomass}$ is absorbed N of whole plant expressed in kg/ha. At the end, the data were analyzed by statistical software MSTAT-C. The means compared by Duncan Multiple Range Test at 5% level.

Results and discussion

Seed yield, total N per plant, N accumulated in seed and N harvest index

The results showed that N fertilizer rate and cultivar had significant effects on seed yield, total N per plant and N accumulated in seed at 1% level, but N harvest index was not affected. Also, the interaction between N and cultivar significantly affected none of these traits (Table 1).

Table 1. Results of analysis of variance of seed yield, N accumulated in plant and N harvest index of rice as affected by nitrogen rates and cultivar.

Sources of variation	df	Seed yield	N accumulated in plant	N accumulated in seeds	N harvest index
Replication	2	213053.03^{ns}	13.194^{ns}	5.528^{ns}	0.002^{ns}
Nitrogen (N)	3	5413315.48**	1653.36**	897.88**	0.002^{ns}
Cultivar	2	1996712.69**	988.86**	545.86**	0.001^{ns}
N × Cultivar	6	110092.51^{ns}	8.19^{ns}	13.38^{ns}	0.002^{ns}
Error	22	1247706.75	15.13	28.28	0.003
C.V. (%)	-	11.8	5.91	25.09	8.73

ns, * and ** show non-significance and significance at 5 and 1% level, respectively.

Means comparison showed that increase in nitrogen rate from 0 to 90 kg N/ha, seed yield was increased by 84.5% (Table 2). Moreover, higher levels of N fertilization induces vegetative growth, increases leaf area index and duration and increases assimilate availability and production potential of panicle per area unit through increasing photosynthesis duration. In addition, N increases flower formation percentage by supplying the protein needed by pollens to move through stigma and reach to ovule, by increasing effective pollination time and helping the formation of stronger embryo sac (Rahemi, 2004). Also, Belder *et al.* (2005), Abou-Khalifa (2012) and Yoseftabar (2013) reported that with increase in nitrogen application, seed yield was increased which is according to result of this research.

Table 2. Means comparison of seed yield, N accumulated in plant and N harvest index of rice as affected by nitrogen rates.

Nitrogen rate (kg/ha)	Seed yield (kg/ha)	Total N content of plant (kg/ha)	N accumulated in seeds (kg/ha)	N harvest index
0	2101.33 d	48.78 d	31.89 d	0.65 a
30	2657.67 c	62.56 c	40.56 c	0.64 a
60	3330.78 b	71.56 b	48.44 b	0.67 a
90	3877.78 a	80.56 a	55.00 a	0.67 a

Treatments with similar letter(s) in each column did not have significant difference at 5% probability level.

Means comparison indicated that cv. Khazar had the highest seed yield which was 31and 16.6% higher as comprised with cultivars Hashemi and Ali-Kazemi, respectively (Table 3). The reason this result was more seed number per panicle of cv. Khazar.

According to the means comparison of N accumulated in plant and seeds at different N fertilizer rates, these traits significantly increased as N rate was increased, so that as it was increased from 0 to 90 kg/ha, N accumulated in plant increased from 48.78 to 80.56 kg/ha (65.1%). In addition, the application of 30, 60 and 90 kg N/ha increased N accumulated in seeds by 28.2, 46.7 and 65.1% compared with no-fertilization treatment, respectively (Table 2).

Obviously, with the increase in N application in field, it becomes more available to the roots and then, the amount of N absorbed by plant as well as its accumulation in seeds increases. It has been proved that a great deal of transferable organic compounds are built during the transition from vegetative to reproductive growth stage, some of which are resulted from the decomposition of proteins of older parts which are transferred to younger growing tissues and seeds as soluble N compounds (Kocheki *et al.*, 1998).

These results are in agreement with the results of Quanbao *et al.* (2007) on rice. Also, Mannan *et al.* (2010) studied the effect of 0, 25, 50, 75 and 100 kg N/ha on four Basmati rice genotypes and find that the application of N up to 75 kg/ha significantly increased N accumulated in seeds but the treatments of 75 and 100 kg N/ha were ranked in the same statistical group.

Table 3. Means comparison of seed yield, N accumulated in plant and N harvest index of rice as affected by cultivar.

Cultivar	Seed yield (kg/ha)	Total N content of plant (kg/ha)	N accumulated in seeds (kg/ha)	N harvest index
Hashemi	2614.25 c	57.75 c	37.67 c	0.65 a
Ali-Kazemi	2936.92 b	64.17 b	43.17 b	0.67 a
Khazar	3424.51 a	75.67 a	51.08 a	0.67 a

Treatments with similar letter(s) in each column did not have significant difference at 5% probability level.

Moreover, Parsertasak and Fukali (1997) stated that although the highest and lowest N harvest index of rice cv. Riukuto-Norin12 (0.69 and 0.62 kg/kg, respectively) was obtained by applying 60 and 180 kg N/ha, respectively, N fertilization treatments had no significant effect on N harvest index that confirmed result current study.

Means comparison indicated that cv. Khazar had the highest N accumulated in plant and seed (75.67 and 51.08 kg/ha, respectively) which was 17.9 and 31% higher as comprised with cultivars Ali-Kazemi and Hashemi with respect to the former and 18.3 and 35.6% higher than them with respect to the latter, respectively (Table 3).

Table 4. Results of analysis of variance of N efficiencies of rice as affected by nitrogen rates and cultivar.

Source of variation	df	N agronomical efficiency	N recovery efficiency	N physiological efficiency
Replication	2	226.317^{**}	818.926^{**}	32.39^{ns}
N	2	8.71^{ns}	338.37^{*}	651.98^{*}
Cultivar	2	188.7^{*}	115.6^{ns}	657.91^{*}
N × cultivar	4	68.25^{ns}	29.87^{ns}	212.86^{ns}
Error	16	34.9	115.05	121.45
C.V. (%)	-	30.17	27.63	22.06

ns, * and ** show non-significance and significance at 5 and 1% level, respectively.

Also, Mannan *et al.* (2010) stated that genotypes exhibited significant differences in N accumulated in seeds.

The non-significance difference in N harvest index at different rates of N and cultivar implies that the share of N transferred to seed out of total absorbed N was not affected by applied N rate and cultivar. Ying *et al.* (1998) reported that N harvest index of high-yielding cultivars of rice was about 0.53-0.69 kg/kg in tropical and semi-tropical zones. In a study on the effect of different N fertilizer rates on late-maturity and mid-maturity cultivars, Singh *et al.* (1998) found N harvest index as 0.36-0.72 kg/kg, but there was no significant difference in N harvest index of some cultivars among N rates.

Agronomical, N recovery and physiological efficiencies

As shown in Table 4, although applied N rate had no significant effect on N agronomic efficiency, it affected N recovery and physiological efficiencies at 5% level. Also, the interaction between N rate and cultivar did not significantly affect these traits.

Although in this research, different N rates had no significantly different in N agronomical efficiency but, there are contrary reports in this regard. Yoshida (1981) stated that N agronomical efficiency was about 15-25 kg/kg applied N in research fields depending on growth season, yield and fertilization timing and rate. In a long-time experiment in IRRI fields, Cassman *et al.* (1996) reported that N agronomical efficiency was 18-30 kg/kg and that it was 15-18 kg/kg in farming fields with conventional farming practices. Also, Talcukdar *et al.* (2002) stated that among the application of three different rates of N (35, 70 and 105 kg/ha) at three phases, the highest N agronomical efficiency (28.57 kg/kg) was obtained with the application of 70 kg N/ha, while the application of 105 kg N/ha decreased it to 20 kg/kg.

Table 5. Means comparison of N efficiencies of rice at different nitrogen rates.

Nitrogen rate (kg/ha)	N agronomical efficiency (kg/ha)	N recovery efficiency (%)	N physiological efficiency (kg/ha)
30	18.54 a	45.78 a	40.35 b
60	20.49 a	36.44 ab	53.04 a
90	19.73 a	34.22 b	56.51 a

Treatments with similar letter(s) in each column did not have significant difference at 5% probability level.

Means comparison of N recovery and physiological efficiencies showed the different effects of N rates on them, so that as N rate was increased from 30 to 90 kg/ha, N recovery efficiency decreased from 45.78 to 34.22% but N physiological efficiency increased by 40% from 40.35 to 56.51 kg/kg (Table 5).

The results of variance analysis showed that rice cultivars had significant differences in their N agronomical and physiological efficiencies at 5% level, but cultivar had no significant effect on N recovery efficiency (Table 4).

Table 6. Means comparison of N efficiencies at different cultivars of rice.

Cultivar	N agronomical efficiency (kg/ha)	N recovery efficiency (%)	N physiological efficiency (kg/ha)
Hashemi	15.35 b	35.00 a	41.95 b
Ali-Kazemi	18.97 ab	39.33 a	48.98 ab
Khazar	24.43 a	42.11 a	57.97 a

Treatments with similar letter(s) in each column did not have significant difference at 5% probability level.

Means comparison showed that agronomic N use efficiency of different genotypes was different and cv. Khazar produced 24.42 kg seed/kg applied N and had the highest N agronomical efficiency which was 28.8 and 59.1% higher as comprised with cultivars Ali-Kazemi and Hashemi, respectively (Table 6). Also the same results was showed in Artacho,s research (2009).

Moreover, Cv. Khazar had the highest N physiological efficiency (58.97 kg/kg) which was 20.4 and 40.6% higher as comprised with the cultivars Ali-Kazemi and Hashemi, respectively (Table 6). Patial *et al.* (2001) reported that N recovery efficiency of rice decreased with the increase in N rate. Also, Limon-ortega *et al.* (2000) on wheat and Gafariani *et al.* (2010) on sorghum reported that N recovery efficiency decreased significantly as N rate was increased which is according to result of this research. Moreover, Yoshida (1981) stated that N recovery efficiency (kg accumulated N in plant per kg applied N) in research fields was about 30-50%. Also, the study in case effect different rates of nitrogen by Quanbao *et al*. (2007) on rice and Gafariani *et al.* (2010) on sorghum indicated that nitrogen physiological efficiency decreased significantly as N rate was increased, which is not according to result of this research.

Conclusion

Given the results of the current study, it can be recommended to use cv. Khazar and N fertilization rate of 90 kg N/ha for the cultivation of rice in Rasht, Iran because it had higher NUE, leaf area and biomass than the cultivars Hashemi and Ali-Kazemi and so, it can produce higher seed yield. Moreover, the increase in applied N rate can significantly increase rice seed yield because of increasing leaf area and duration and hence, increasing photosynthesis potential.

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