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Dry matter accumulation and nitrogen use efficiency response of rice cultivars to nitrogen management

MandanaTayefe*

Department of Agriculture, Lahijan branch, Islamic Azad University, Lahijan, Iran

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Key words: Rice, Nitrogen fertilizer, Nitrogen use efficiency, Dry matter accumulation.

Abstract

Irrigated rice in Iran involves global rice production and global nitrogen (N) consumption. The low agronomic N use efficiency (kg grain yield increase per kg N applied) of this system is below. So the objective of this study was to determine the possibility to improve the N use efficiency of irrigated rice in Iran by comparing the farmers' N-fertilizer contents usage. Field experiments were conducted three rice cultivars (Hashemi, Kazemi, Khazar) in a completely randomized block design with 3 replications were used to study the effects of nitrogen fertilizer on nitrogen use efficiency, yield and characteristics of nitrogen uptake during two years (2008-2009) in paddy soil in Guilan province, Iran. In this experiment, four treatments including: N1-control (no N fertilizer); N2- 30 kg ha^{-1} N (at transplanting time); N3- 60 kg ha^{-1} N (at transplanting, and tillering times); N4- 90 kg ha^{-1} N were compared. Results showed that the effect of N application on yield increasing was remarkable whereas N4 created the highest yield (3662kg ha^{-1}). Dry matter, total N uptake, physiological Nitrogen use efficiency (PNUE), apparent nitrogen recovery efficiency (ANRE) and agronomic nitrogen use efficiency (ANUE) was varied in different cultivars significantly and Khazar variety had the highest contents. Maximum dry matter and total N uptake were achieved mostly at 90 kg N ha^{-1}, which were significantly higher than other treatments .Physiological N use efficiency (PNUE), agronomic nitrogen recovery efficiency (ANRE) increased from zero nitrogen to 30kg N ha^{-1} significantly and the result were reversed from N2 to high content of nitrogen application (90 kg N ha^{-1}).

***Corresponding Author:** Mandana Tayefe ✉ m.tayefe@yahoo.com

Introduction

Crop yields in the world have continuously increased to meet population growth, partly because of the increase in fertilizer nutrient input, especially N fertilizer (Cassman *et al.*, 2003). Nitrogen is normally a key factor in achieving optimum lowland rice grain yields (fageria *et al.,* 1997). Soils under these conditions are saturated, flooded, and anaerobic and N use efficiency is low. Under these situations, increasing rice yield per unit area through use of appropriate N management practices has become an essential component of modern rice production technology. To maximize grain yield, farmers often apply a higher amount of N fertilizer than the minimum required for maximum crop growth (Lemaire and Gastal, 1997). Nitrogen use efficiency is relatively low in irrigated rice because of rapid N losses from ammonia volatilization, denitrification, surface runoff, and leaching in the soil– floodwater system. The magnitude and nature of N losses vary depending on the timing, rate, and method of N application, source of N fertilizer, soil chemical and physical properties, climatic conditions, and crop status.

In general, ammonia volatilization is the major pathway of N loss in irrigated rice (Zhu, 1997 This means, low recovery of N fertilizer not only increases cost of production but also may contribute to ground water pollution. Adoption of proper management strategies of N fertilizer, such as adequate rate and timing of application and use of N efficient crop genotypes, may reduce cost of production and at the same time improve rice yield. The objectives of this study were: study commercial varieties of rice response to N fertilization, and estimate dry matter production, N uptake, and N use efficiency at two years and four N rates.

Material and methods

Field experiment site

The field experiment was conducted at Rice Research Institute, Rasht, Guilan, Iran, during the growing season 2008 and 2009.

Fertilizer treatments

The experiment was laid out factorial in randomized complete block design with three replications of four nitrogen fertilizers levels (N1-control (no N fertilizer); N2- 30 kg ha^{-1} N; N3- 60 kg ha^{-1} N; N4- 90 kg ha^{-1} N.

Rice cultivar

Three different varieties were examined (Hashemi: V1, Alikazemi: V2 and khazar: V3). The N fertilization was applied as single incorporated application of urea (46% N).

Sampling and analysis

Plant and grain nitrogen concentration was determined by the methods of micro-Kjeldal digestion, distillation, and titration (Fageria *et al*, 2009).

Definitions and N equations for calculating N use efficiencies are given in Table . (Quanbao *et al*, 2007).

Statistical analysis

Factorial analysis of variance were conducted using General Linear Model procedure in the SAS package (SAS, 1990) to determine the significance of the effects of N fertilization, cropping varieties, year and their interactions on grain yield, N uptake, and NUE indices. Polynomial regression analyses were used to test treatment effects. Appropriate regression equations were selected on the basis of level significance and R^2 values.

Results

Grain yield & Dry matter accumulation

Data investigation showed that, there was significant influence of nitrogen fertilizer rate and varieties on grain yield (Table 2). Average data of two years showed that Khazar variety produced maximum yield (3414kg ha^{-1}) and downloaded Kazemi was second in grain yield. Overall, difference in grain yield was 1751 kg ha^{-1} between highest yield producing Khazar and lowest yield producing Hashemi.

There was significant influence of year, N rate and varieties on total biomass (Table 3). Effect of different amount of nitrogen fertilizer on dry matter (DM) was significant (table 2), as in N4 treatment (90 kg N ha^{-1}) had the highest total biomass (8386kg ha^{-1}) (Figure1).

Grain N-uptake, straw N-uptake and total N-uptake

Nitrogen uptake in grain had a significant response to N fertilization and different varieties (Table 4). Grain N-uptake increased significantly with N. Khazar variety accumulated maximum N (52.41 $kgha^{-1}$) in the grain (Table 5).

Table 1. Definitions and methods of calculating nutrient use efficiency.

Nitrogen harvest index (NHI)	grain N uptake / total plant N uptake
Apparent N recovery efficiency (ANRE)	(total plant N uptake with N application-total plant N uptake without N application) / N application × 100.
Agronomic N use efficiency (ANUE)	(grain yield with N application-grain yield without N application) / N application
Physiological N-use efficiency (PNUE)	(grain yield with N application-grain yield without N application) / (total plant N uptake with N application-total plant N uptake without N application)

Nitrogen uptake in the straw differs significantly between 0 and 90(kg N ha^{-1}). As N4 (90kg N ha^{-1}) caused the highest content of N uptake (57.16 kg ha^{-1}). In N4 treatment (90 kg N ha^{-1}), the highest straw-N uptake was observed (22.16 kg ha^{-1}) and the lowest content (12.61 kg ha^{-1}) belonged to N1 (0 kg N ha^{-1}) (Table 5).

Table 2. Grain yield (kg ha−1) of 3 lowland rice varieties across 4 N rates.

Varieties(V)	1st year	2nd year	Average
Hashemi	2724	2603	2664
Kazemi	2905	2882	2893
Khazar	3580	3250	3415
F-test			
Year(Y)	ns		
N rate(N)	**		
Varieties(V)	*		
Y*N	ns		
Y*V	ns		
N*V	ns		
Y*N*V	ns		

*, **, NS Significant at the 5 and 1% probability level and non-significant, respectively. Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

Straw N-uptake increased with nitrogen increasing, significantly. But result of variance analysis at 1% confidence level revealed that nitrogen uptake in straw had no significant response to variety (Table 4). Result of variance analysis at 1% confidence level revealed that nitrogen uptake in total had a significant response to N fertilization (Table 4). N4 treatment (90 kg N ha^{-1}) caused the highest total-N uptake was observed (79.38 kg ha^{-1}) (Table 5).

Result of variance analysis at 1% confidence level revealed that total nitrogen uptake had significant response to variety (Table 4).As Khazar variety produced highest nitrogen-N uptake (71.54 kg ha^{-1})(table 5), Also the lowest content of total-N uptake belonged to Hashemi variety (57.37 kg.ha^{-1}).

N use efficiency

Effect of N on N harvest index was not significant (table 4), but NHI of rice was decreased with increasing N application (Table 6).

Table 3. Total biomass (kg ha−1) of 3 lowland rice varieties across 4 N rates.

Varieties(V)	1st year	2nd year	Average
Hashemi	6878	5070	5974
Kazemi	7229	5450	6340
Khazar	8406	7062	7277
F-test			
Year(Y)	*		
N rate(N)	**		
Varieties(V)	*		
Y*N	Ns		
Y*V	Ns		
N*V	Ns		
Y*N*V	Ns		

*, **, NS Significant at the 5 and 1% probability level and non-significant, respectively. Means followed by the same letter in the same column are not significantly different at the 5% probability level by Tukey's test.

Apparent N recovery efficiency (ANRE) was the primary index to describe the characteristics of N uptake and utilization in rice. Most researchers considered that this description accorded with the fact of rice production. Result of variance analysis at 1% confidence level revealed that ANRE had not significant response to nitrogen (Table 4). As data indicated that ANRE of rice was decreased with increasing N application significantly (table 6). N2 created the most ANRE (0.49) while, by using maximum nitrogen fertilizer, ANRE decreased (0.37). Agronomic N use efficiency (ANUE) result of variance analysis at 1% confidence level revealed that ANUE had no significant response to nitrogen (Table 4). Examining the comparison of average in confidence level 5% specified that among the different content of nitrogen fertilizer, the most ANUE belonged to N2 (20); however, by increasing nitrogen fertilizer rate from N2 to N4, ANUE decreased (table 6).

Table 4. Significance of the F values from the analysis of variance for rice parameters.

Parameters	Nitrogen (N)	Variety (V)
grain N-uptake	**	**
straw N-uptake	*	Ns
total N-uptake	**	*
NHI	ns	Ns
ANUE	ns	**
PNUE	*	*
ANRE	**	*

*, ** = significant at the 0.05 and 0.01 probability levels,
Respectively; ns = not significant.

Physiological N use efficiency (PNUE) result of variance analysis at 1% confidence level revealed that PNUE had no significant response to nitrogen (Table 4). Results from comparisons of average of studied property in different amount at confidence level 5 % are also shown (Table 6). N2 created the most PNUE (53) while, by using maximum nitrogen fertilizer, PNUE decreased (40.5) significantly. Generally analysis of data indicated that, PNUE of all varieties was decreased with increasing N application significantly (table 6).

Table 5. Results of comparison of average of studied variables between chemical fertilizer contents in confidence level of 5%.

Variable	Grain -N uptake	Straw-N uptake	Total- N uptake
2008	47.47a	19.77a	64.61a
2009	44.77a	14.72b	62.19a
N1	33.22c	12.61c	45.77c
N2	42.16b	16.33bc	58.55b
N3	51.94a	17.88b	69.88a
N4	57.16a	22.16a	79.38a
V1	41.50c	15.83a	57.37b
V2	44.45b	16.75a	61.29b
V3	52.41a	19.16a	71.54a

Discussion

Basis on yield data was revealed maximum yield (3662kg/ha) was obtained with the higher N rate (90kgN/kg), with detecting yield decrease in the range of rates tested (Figure 1). Quanbao *et al* (2007) showed that grain yield was increased obviously with increasing N application and reached the maximum when N application was 225 kg ha^{-1}.

Table 6. N use efficiency indices for rice varieties for the different treatments of 5%.

N rate (kg ha-1)_	NHI		ANRE		ANUE		PNUE	
	2007	2008	2007	2008	2007	2008	2007	2008
0	69a	76a						
30	67a	77a	0.47a	0.51a	20.01a	19.96a	58.53a	48.47a
60	71a	77a	0.33b	0.47b	18.47a	20.28a	55.57a	49.16a
90	69a	75a	0.35b	0.49b	14.25a	18.36a	36.73b	45.76b

In Brazilian Inceptisols about 90 kg N ha^{-1} was recommended for lowland rice (Fageria *et al*, 2001). This N rate is considered economic rate as defined by 90% of the maximum yield index (Fageria *et al*, 2001). In general Yoshida (1983) believed that grain yield in rice is the product of different yield components. Also Singh *et al* (1998) showed that the relative importance of each component varies with location, season, crop duration, and cultural system. Varieties differences in lowland rice grain yield have been widely reported and these differences may be associated with difference in yield components of different genotypes (Fageria *et al*, 2001; Fageria *et al*, 2003).

Data investigation confirmed that for three varieties, total (straw plus grain) dry matter production had a significant quadratic response to N fertilization. Average of two years results showed that nitrogen fertilizer by increasing of nitrogen content (from N1 to N4) biomass increased While N4 created the most total biomass (8386 kg .ha^{-1}). Artacho *et al* 2009 described that total biomass production had a significant response to N fertilization, too.

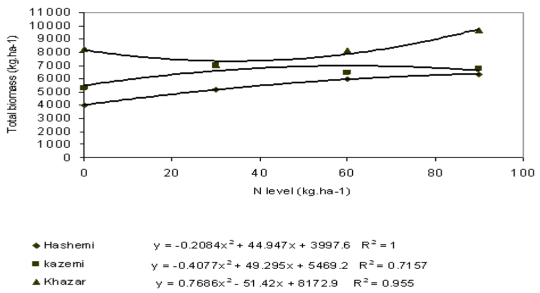

Fig. 1. Total biomass (dry matter) of three lowland rice varieties as influenced by nitrogen fertilization.

Chaturvedi *et al*, (2005) showed that dry matter accumulation increased significantly with N fertilizer application in rice at all the growth stages of the crop. N fertilizer application, in addition to water, is considered to be the most important input for biomass production in rice at all the growth stages of the crop. (Chaturvedi, 2005)

The influence of the nitrogen treatment on performance of nitrogen uptake were also defined a main parameters of fertilizers selecting. A great part of the applied N is escaped to the environment through denitrification and volatilization (Delacruz *et al.*, 1994).

Studying of data revealed that grain N uptake increased with nitrogen fertilizer increasing. This may be associated with maximum yield. Fageria *et al*, (2003), Osaki *et al*, (1992) and Shinano *et al*, (1995) reported that in cereals including rice, N accumulation is associated with dry matter production and yield of shoot and grain.

In both years, grain yield was significantly and quadratically related with N uptake in grain ($R^2 > 0.98$ and $R^2 > 0.91$, respectively in 2008, 2009) (Figure 3), indicating that, in most cases, higher grain yield would be due to higher N uptake. Also Fageria *et al* (2009) showed that Nitrogen uptake in shoot was having quadratic relationship with grain yield in the range of 14 to 90 kg ha^{-1}.

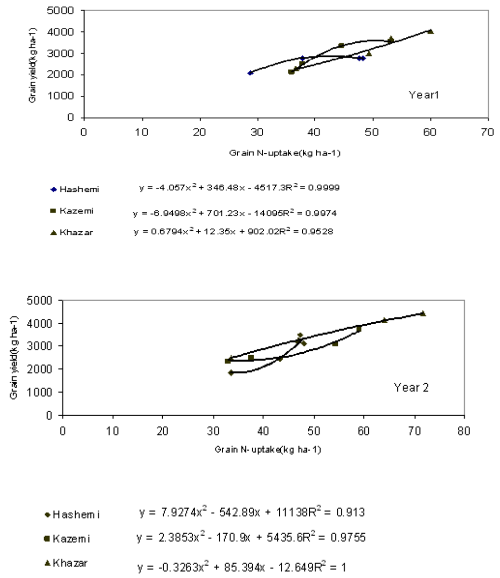

Fig. 2. Relationships between grain N uptake and grain yield at physiological maturity for rice, for two years.

Results of data showed in all of treatments Nitrogen uptake of straw is lower than grain uptakes too. As by using of nitrogen fertilizer the most grain and straw N uptakes are created in N4 (22.16 kg ha^{-1}). Fageria *et al* (2009) believed that this may be associated with maximum yield of shoot yield.

N accumulation at maturity in rice organs indicated that N accumulation in straw; grain and plant were remarkably affected by N application. N accumulation in grain was increased remarkably with increasing of N application because grain yield increased quickly then slowed down because grain yield increased slowly. By contrast, N accumulation in straw was increased gradually because of the quickly increasing of straw yield. Total N accumulation in rice plant also showed the trend of increasing. Genotypic differences were also existed among the rice cultivars too. N distribution in grain was higher than that in straw for all treatments. The concentration in straw was increased significantly while it declined in grain with increasing N application. It indicated that N application can improve N translation from nutrition organs to grain, but more N was left in nutrition organs because of the decreasing N translation rate and led to an excessive uptake of N by rice plant, and decreases in NHI and nitrogen use efficiency (Quanbao *et al*, 2007).

NHI Data analysis indicated that the N ratio in straw enhanced with increasing N application and it led to rice plant uptake N excessively. This result was similar to that of Quanbao *et al* (2007). Artacho *et al* (2009) in his research showed that N harvest index was not affected significantly with N fertilization.

Evaluation of data revealed decreasing of ANRE with increasing of nitrogen fertilizer. Quanbao *et al* (2007) showed that ANRE was increased with increasing of N application in sandy soil while it was increased firstly and reach to the maximum under 225 kg ha^{-1} N application, then declined significantly under 300 kg ha^{-1} N application in clay soil. It indicated that it was not useful for improvement of ANRE with more or less N application. In addition, a negative correlation between NUE g and N concentration in grain and straw at maturity has been found (Singh *et al.* 1998; Koutroubas and Ntanos 2003). Also lower N concentration in grain or straw indicates that a higher proportion of acquired N was used to generate them.

Agronomic efficiency may be defined as the nutrients accumulated in the above-ground part of the plant or the nutrients recovered within the entire soil-crop-root system. Nutrients not used by the crop are at risk of loss to the environment, but the susceptibility of loss varies with the nutrient, soil and climatic conditions, and landscape. Studying of ANUE data indicated that the capability of yield increase per kilogram pure N declined remarkably with increasing N application. As agronomic N use efficiency of different genotypes was different. ANUE of all genotypes was decreased significantly. Also the same results were showed in Artacho‚ s research (2009). Also Lopez-Bellido *et al.* (2000) suggest that ANUE decreases because the increase in N uptake is higher than the increase in grain yield. In addition According to the relationship between soils conditions under different fertilizers and rice production, adjustment of N practice aiming at improving the potential of soil production could increase N use efficiency and rice grain yield (Artacho *et al.* 2009). Low N use efficiency is also related to Nitrogen deficiency by the crop due to loss by leaching, volatilization, disnitrification and erosion (Fageria *et al.* 2010).

Data studying showed decreasing of PNUE with increasing nitrogen fertilizer. Quanbao *et al* (2007) in the same research showed that under two soil conditions, PNUE of all genotypes was decreased significantly with increasing N application. Compared to PNUE under two soil conditions, it was higher in sandy soil than that in clay soil.

Conclusion

From the present study of chemical rice cultivation, it can be concluded that cultivation practices in farming that lead to greater inputs of N in the soil improve the nutrient availability to the crop.

Nitrogen fertilization significantly increased grain yield but response varied in different varieties. Khazar variety was most efficient in grain yield production compared with other varieties. Nitrogen uptake in grain was having significant association with grain yield. Hence, it can be concluded that differences in N uptake efficiency among lowland rice varieties is an important trait in improving yield and reducing cost of N lowland rice production. Total N uptake, physiological Nitrogen use efficiency (PNUE), Apparent Nitrogen recovery efficiency (ANRE) and Agronomic Nitrogen use efficiency (ANUE) was varied in different cultivars significantly. But Dry matter, total N uptake increased with increasing in N fertilizing contents but physiological N use efficiency (PNUE), Agronomic Nitrogen use efficiency (ANUE) decreased. And difference between nitrogen harvest index (NHI) contents in different varieties and various nitrogen fertilizer rates was not significant.

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