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Nutrient-use efficiency in rice (*Oryza sativa*) in coastal tract of Odisha*

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Under wide variation of rice ecosystem, the applied plant nutrients are being lost in different pathways like leaching, surface runoff, ammonia volatilization, denitrification and the efficiency of applied nutrients becomes very low (Dobermann 2005, Lodha *et al.* 2005, Kapoor *et al.* 2008, Chien *et al.* 2009, Li *et al.* 2009). Due to vagaries of climatic changes with erratic distribution of rainfall, development of alternate wetting and drying of submerged and non-submerged water regimes results into low nutrient-use efficiency (Belder *et al.* 2005). During the crop growth period receipt of inadequate rainfall establishes moisture stress; changes N dynamics and stimulate N loss. Such type of ecosystem of alternate wetting and drying generally occurs in rice-growing areas (Bouman *et al.* 2002). In this eastern region of India where total annual rainfall is very high and 80–90% of annual rainfall is dominated during rainy season, it is highly imperative to assess effectiveness of applied plant nutrient to rice crop production as different rice varieties respond to its rate of application under various rice ecosystems. Considering these constraints, the project was taken up in the farmer's field in distributory No. 5 of Patmundai canal in Mahanga block of Cuttack district of Odisha during rainy (*kharif*) season of 2004–05 and 2005–06 with two short-duration paddy varieties and different fertilizer doses.

The study was conducted at Manitri village (long. 20 ° 59', latitude 86 ° 22') of Mahanga block, Cuttack district of Odisha. It falls in the middle reach of Pattamundai Canal distributary No.5 having cultural command area of 751 ha (Mahanadi Delta I). In this village canal water supply is not available for early planting of rice and subsequent *rabi* crop during winter season. Hence bore well was made on participatory basis (50:50 share of total expenditure) and early planting of rice seedling was done as farmers were earlier growing rice through broadcasting method, followed by green gram with pre-sowing heavy irrigation through canal water. During rainy season, short-duration rice varieties, viz. Anjali (V1) and Khandagiri (V2) in crop geometry of 20 cm × 15 cm were transplanted in first week of July 2004 and 2005 and harvested in first week of October in respective years. These varieties were tested to assess N response on yield and nutrient-use efficiency. Nitrogen as per level was applied in three splits 1/3 each at planting, 25–30 days and 45–50 days after planting; however common dose of phosphorus and potassium was applied at planting only. After planting water depth in plot was monitored to assess duration of moisture stress (disappearance of standing water in plot). In the process of submergence/ saturation and moisture stress, nutrient dynamics in field and availability to plants depends. The amount of rainfall received and pan evaporation; maximum and minimum temperature recorded at nearby meteorological station, i e Central Rice Research Institute, Cuttack (Odisha) were used for interpretation of the results. The computation of reference ETo has been computed as per equation given by Allen *et al.* (1998). During July, August and September 2004, total rainfall received was 381.2, 249.2 and 596.8 mm and in 2005 in corresponding months it was 396.5, 642.6 and 395.4 mm. As against this rainfall, total reference ETo during above mentioned month in 2004 was only 109.9, 108.8 and 111.3 mm and during 2005, it was 123.7, 116.6 and 121.5 mm. The maximum and minimum temperature was also quite favourable to rice crop. The experimental field was sandy loam up to 0–30 cm depth and loam beyond this layer. The infiltration rate was moderate. With regards to nutrient status, the experimental field was low in nitrogen (179 kg/ha), medium in phosphorus (14.4 kg/ha) and potassium (166.5 kg/ha) in 0–60 cm soil depth. The soil *p*H was acidic in reaction (*p*H 6.0) and total salts were also quite low (EC 0.51 dS/m) and hence the EC was low. The water quality used for irrigation was also good as it is expressed in terms of *p*H and EC.

The crop yield, soil and plant nutrient uptake and its response were analyzed. To obtain economic dose of nitrogen under rainfed condition, grain yield was regressed with nitrogen levels and the coefficients obtained was used to

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estimate optimum N dose with the following equations.

$$Y= a+bx+cx2$$

Optimum dose (kg N/ha) = {(1/2c)* (PnPk)-b}

Where b is linear coefficient and c is quadratic coefficient, Pn is price of nitrogen ₹ /kg (₹ 10.4) and Pk is price of grain ₹/kg (₹ 7.50).

Apparent N recovery, agronomic efficiency and physiological efficiency were also computed by using grain yield, nutrient uptake in grain and straw with the following equations.

1. Apparent N recovery (%) from total N uptake (grain + straw)= (N uptake in fertilized plot) - (N uptake in control plot)/ N applied) × 100 as described by Crasswell and Godwin (1984).
2. Agronomic efficiency (kg grain/ kg of applied nutrient) as defined by Ladha *et al.* (2005) = (grain yield in fertilized plot) - (grain yield in control)/N applied
3. Internal nitrogen-use efficiency or physiological efficiency (kg grain/ kg of N uptake) as defined by Witt *et al.* (1999).

= (yield of grain from fertilized plot) - (yield of grain from control plot)/N uptake

The experimental results presented in Table 1 revealed that rice variety Anjali outyielded Khandgiri and the effect was highly significant. The magnitude of increasing grain yield was 11.9% in pooled data. Similar was the trend with respect to straw yield in which the increasing straw yield was 11.8% in Anjali variety.

The nitrogen applied in rice field generally enters into several pathways of nitrogen losses and leaching loss is quite high in these soils as sandy loam soil allows more loss of water through infiltration. It has been observed that the increasing nitrogen level from unfertilized control to 60 kg N/ ha with increment of 15 kg N/ ha, enhanced overall crop growth and yield. In unfertilized control plot, grain yield was only 1.75 tonnes/ha and at 30, 45, and 60 kg N/ ha, the increase in yield was 29.7, 61.7and 99.4% respectively. Similarly, in 2004 and 2005 crop seasons the increase in grain yield over unfertilized control was 32.3% to 28.7% in 30 kg N/ ha, 65.9% to 68.3% in 45 kg N/ ha and 104.7% to 94.4% in 60 kg N/ ha dose. The magnitude of enhancement of straw yield with application of nitrogen was found to the tune of 37.5%, 79.7% and 130.1% in 30, 45, and 60 kg N/ ha, dose respectively in pooled. Similar trend were recorded during both the years.

The experimental results on nutrient uptake by rice revealed that on an average of two years, the variety Anjali absorbed 12.1% higher nitrogen, 17.8% phosphorus and 11.5% potassium as compared to variety Khandgiri. In individual year also the trend of absorption rate of N, P, and K was similar but with varying magnitude. During 2004, nutrient absorption rate was higher by 10.9% in nitrogen 23.4% in phosphorus and 10.2% in potassium in rice variety Anjali than Khandgiri. During 2005, similar trend was observed and the magnitude of absorption rate was 13.2% in nitrogen 12.3% in phosphorus and 12.9% in potassium. With respect to differential amount of nitrogen application on nutrient uptake, the uptake rate of all three major plant nutrients increased with increasing nitrogen application dose from unfertilized control to 60 kg N/ ha. On an average of two years, total nitrogen uptake (grain and straw) in control was 27.02 kg / ha. With increasing nitrogen

Table 1 Effect of varieties and nutrient levels on rice yield, nutrient uptake and nutrient-use efficiency (pooled data of 2004–05 to 2005–06)

Treatment	Yield (tonnes/ha)		Nutrient uptake in grain (kg/ha)			Nutrient uptake in straw (kg/ha)			Use efficiency		
	Grain	Straw	N	P	K	N	P	K	Apparent N recovery (%)	Agronomic efficiency (kg grain/kg of applied N)	Physiological efficiency (kg grain/kg of N uptake
Variety											
V_1	2.73	3.97	29.95	5.24	9.74	16.84	3.11	55.60	31.57	25.15	78.87
V_2	2.44	3.55	26.89	4.25	8.70	14.85	2.84	49.88	25.62	21.73	84.37
SEm	0.031	0.045	0.34	0.05	0.10	0.20	0.03	0.62	0.95	0.90	0.26
LSD (0.05)	0.189	0.273	2.09	0.35	0.66	1.23	0.21	3.80	3.04	2.23	0.67
Nitrogen (kg/ha)											
N_O	1.75	2.32	18.27	2.81	5.60	8.75	1.56	31.77			
N_{30}	2.27	3.19	24.76	4.03	7.76	13.18	2.47	44.49	21.64	17.22	79.18
N_{45}	2.83	4.17	31.38	5.33	10.27	17.97	3.34	58.7	29.13	24.07	82.73
N_{60}	3.49	5.34	39.28	6.82	13.26	23.50	4.53	76.00	35.01	29.03	82.96
SEm	0.053	0.077	0.58	0.09	0.18	0.33	0.06	1.07	1.76	1.61	0.89
LSD (P=0.05)	0.165	0.237	1.80	0.29	0.58	1.03	0.18	3.31	6.09	5.57	3.09
Interaction											
SEm	0.076	0.109	0.82	0.13	0.26	0.47	0.08	1.52	3.05	2.79	1.55
LSD (P=0.05)	NS	NS	2.55	0.41	0.82	1.46	0.26	4.48	10.55	9.65	5.36

level there was progressive increase in N uptake and was recorded to the extent of 28.8%, 82.6% and 132.7% in 30,v45 and 60 kg N /ha dose respectively. During 2004 nitrogen uptakes in above N levels were 46.25%and 35.2% and 92.1% and in 2005, 74.0% and 145.6% and 120.4% higher than control respectively. The phosphorus uptake also had similar trend with magnitude of 48.7%, 98.4% and 157.7% in pooled data and 55.4 - 42.7%, 104.7 - 93.0% and 181.4 - 141.3% in first and second year respectively. In case of potassium uptake 39.8%, 84.6% and 138.8% more K uptake was noticed in 30, 45, and 60 Kg N / ha respectively over control in pooled analysis. During 2004 and 2005 crop seasons, potassium uptake in 30 kg N /ha dose was enhanced by 44.5% and 37.3% over control. With further increasing nitrogen level to 45 and 60 kg N/ha dose the increase in potassium uptake was 88.6 - 83.2% and 87.75 - 137.3% in first and second year of experimentation respectively. Potassium uptake in straw was quite high as compared to grain and the ratio ranged from 5.71 and 5.73 in Anjali and Khandagiri respectively. In case of differential amount of N application, uptake pattern in straw and grain was affected and the ratio was found to be 5.67, 5.73, 5.73, 5.73 in control, 30, 45 and 60 kg N /ha dose respectively.

The results presented nitrogen-use efficiency parameter reveals that the amount of nitrogen recovered by the plant on an average of two years was 25.6% to 31.6% in two varieties and maximum was observed in variety Anjali. With respect to differential amount of nitrogen application, increasing nitrogen level though increased recovery of nitrogen but its magnitude declined with increasing nitrogen level (Table 1). This type of trend generally prevails when deficit amount of any plant nutrient exist in soil or growing media. To meet daily needs of plant nutrient for growth and development plant tries to extract maximum nutrient from soil and hence recovery per cent was not increased linearly with each increment of nitrogen levels. Similar trend was observed in both the year of experimentation. The agronomic efficiency was higher in variety Anjali (25.1 kg/ kg of applied N) than Khandagiri (21.7 kg/kg of applied N). Application of lower amount of N had minimum agronomic efficiency than higher amount of N however the magnitude of increasing agronomic efficiency was in linear trend with increasing nitrogen application rate in both varieties. In case of physiological efficiency (kg grain yield/kg of N uptake), the variety Khandagiri responded quite satisfactory and produced more grain yield by absorbing a unit kg of applied nitrogen. Application of differential amount of nitrogen level had very low impact on physiological efficiency as increasing nitrogen level from 30 to 60 kg/ha did not show any significant improvement on this parameter. Belder *et al.* (2005) conducted field experiment at Tuanlin (China) during summer 2000–03 and at Munoz in Philippines during dry season of 2001 in rice. They maintained continuous shallow submergence and alternately submerged non-submerged regimes with two levels of nitrogen (0 and 180 kg N/ha at Tuanlin and 90 and 180 kg/ha at Munoz) and monitored nitrogen recovery, agronomic efficiency and physiological efficiency. The biomass and apparent recovery declined linearly under submergence-non submergence water regimes. The internal N-use efficiency was very high in control plot as compared to 180 kg N/ha under submerged condition and it was further increased under submergence non-submergence condition. With respect to nitrogen-use indicators, internal N-use efficiency was very high in control and was reduced linearly with increasing nitrogen level to 90 and 180 kg N/ ha dose.

To estimate economic dose of nitrogen in rice crop the yield of rice varieties was regressed with different amount of nitrogen application in second degree polynomial equation considering yield is dependent variable and nitrogen independent variables. The coefficient derived was then used to estimate optimum level of nitrogen with following equation.

2004–05	$Y = 1.3405 + 0.2736X - 0.0004 X^2$	r^2 0.84
2005–06	$Y = 1.5383 + 0.2105 X + 0.0048 X^2$	r^2 0.78
Pooled	$Y = 1.4377 + 0.2441 X + 0.0020 X^2$	r^2 0.81

Where, Y is expected grain yield in tonnes /ha and X is nitrogen level in kg/ha.

From the above three-equations, only first year equation showed the decreasing trend with increasing nitrogen level as the quadratic coefficient 'c' is negative. But due to very minor declining rate under this soil and climatic conditions the crop needs more amount of nitrogen level tested in this experiment because during crop growth period most of the applied nitrogen is lost through leaching due to continuous standing water in field for longer period and heavy rains in one or two occasions.

SUMMARY

In upland situation, farmers prefer very short-duration rice varieties and maintain the field with saturation to shallow submergence by creating small dyke height.

During high rainfall period, most of the applied plant nutrient goes as deep percolation loss and surface runoff as very small amount is lost in ammonia volatilization due to acidic in nature. The experimental site prevailed to undergo such type of loss mechanism and hence the response to the highest amount of applied nitrogen was linear and nitrogen recovery was as low as 35% as compared to 51% from 800 experimental data of cereal crops used by Dobermann (2005). So the utilization of applied nitrogen through various management practices like split application, placement of fertilizer in reduced zone and maintenance of saturation throughout the crop growth period is highly essential to improve fertilizer-use efficiency in rice crop.

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