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Nitrogen Dynamics in Soil as Influenced by Long-term Manuring and Fertilization under Rice Grown on Vertisol of Chhattisgarh

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Effect of nutrient management practices on nitrogen (N) dynamics in rice grown on a Vertisol was studied after 16 years in an ongoing long-term experiment initiated during 1999-2000. The experiment comprised of different levels of NPK fertilizers alone and in combination with farmyard manure (FYM), blue green algae (BGA) and green manuring (GM) was laid out in split-plot design with four replications. Application of 100% NPK + FYM (5 t ha^{-1}) significantly increased the organic N fractions *viz*., hydrolysable NH_4^+-N (165 mg kg^{-1}), amino acid-N (271 mg kg^{-1}), amino sugar-N (36.8 mg kg^{-1}) and hydrolysable unknown-N (127 mg kg^{-1}). The mineral N (nitrate-N + ammonium-N) content (57.3 mg kg^{-1}) was significantly increased with the application of 100% NPK + FYM. A decrease in N fractions was observed with advancement of crop growth stage and increase in the depth of soil from 0-15 to 15-30 cm. The contribution of inorganic and organic N fractions to total N was noted to the extent of 7 and 73%, respectively under 100% NPK + FYM, whereas comparatively lower contribution of these fractions was recorded in control treatment. The contribution of hydrolysable unknown N (HUN) to total hydrolysable N ranged between 21 to 31%, the highest contribution was noted in control (31%) and least contribution was recorded in 100% NPK + FYM. The grain yield (6.45 t ha^{-1}) of rice was increased significantly with the combined application of manures and fertilizers. The total uptake of N by rice was increased significantly with the conjoint use of fertilizers and organic manure. The N recovery efficiency was decreased with increasing fertilizer levels. The rice grain yield was significantly correlated with various N fractions; the highest correlation coefficients among organic N fractions observed with total hydrolysable N at maximum tillering and harvest were $r = 0.698^{**}$ and $r = 0.610^{**}$ in surface and $r = 0.635^{**}$ and $r = 0.593^{**}$ in sub-surface layer of soil, respectively. The mineralizable N was significantly correlated with all fractions of N, except with HUN and non-hydrolysable N. The multiple regression analysis indicated that hydrolysable NH_4^+-N and HUN are dominant N fractions in contributing rice grain yield and N uptake.

Key words: Amino acid-N, amino sugar-N, hydrolysable NH_4^+-N, inorganic-N, rice

Nitrogen (N) is the most important mineral nutrient affecting the growth and yield of crops and its adequate supply in the soil in forms which roots can take up is essential for high yields. The term "N dynamics" includes the distribution and transformation of organic and inorganic N forms as well as their atmospheric and biospheric interrelations (Stevenson 1982). Over 90% of total N occurs in organic forms in the surface layer of most soils. Soil organic N (SON) plays a key role in terms of plant nutrition through direct and indirect effects on microbial activity and nutrient availability. Knowledge about the amounts and distributions of the organic forms of N, therefore should contribute to a better understanding of the soil productivity (Bremner 1965c). Inorganic N forms (mainly NH_4^+-N and NO_3^--N) in soils are the available forms that plants and microorganisms can use, but excess of NO_3^--N can move below the root zone as water moves through it in rice fields. The efficient use of fertilizer N for crop production depends on the several transformations that fertilizer N may undergo. Application of farmyard manure (FYM) has received

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great attention from soil scientists' because it is available in large quantities and it directly and indirectly affects crop growth and yield as well as soil properties. Judicious use of fertilizers along with organic manures affect the amounts and distribution of organic N forms in soils. Prieto *et al.* (1997) reported that most of the added urea N was transformed into hydrolysable organic N fractions which were the major sources of plant available N. The continuous addition of organic manures along with fertilizers may stimulate mineralization and immobilization of plant nutrients (Srivastava and Lal 1998) thereby affecting their amount in different organic and inorganic forms in soil. Understanding the effect of continuous manuring and fertilization on the transformation and behavior of N forms is pre-requisite for precise N management under intensively grown rice-wheat cropping sequence in Vertisols of Chattishgarh. Therefore, the present investigation was carried out to study the long-term effect of nutrient management on various N fractions and their relative contribution to yield of rice and N uptake.

Materials and Methods

A long-term field experiment on rice-wheat cropping sequence was initiated during 1999-2000 at Instructional Farm, Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Viswavidyalaya (IGKV), Raipur, Chhttisgarh. The treatments comprised 10 different combinations of manures and fertilizers (Table 1).

The recommended dose of fertilizers for rice and wheat were 100: 60: 40 kg N, P_2O_5 and K_2O ha^{-1}. In T5, 10 kg Zn ha^{-1} as zinc sulphate was applied to rice only. In T8, FYM at 5 t ha^{-1} (dry weight basis) was applied to rice. In T9, rice field was inoculated with blue green algae (BGA) at 10 kg ha^{-1} (dry weight basis) and the biomass was incorporated into the soil at 10 days after rice planting. In T10, *Sesbania* (*dhaincha*) was grown in-situ for 45 days and biomass was incorporated into the soil at 2-3 days before rice transplanting. No fertilizer was applied to *Sesbania*. The nutrient content of FYM and GM crop is given below:

Table 1. Treatment details

Tr.	*Kharif* rice	*Rabi* wheat
T1	No manures and fertilizers (Control)	No manures and fertilizers (Control)
T2	50% NPK	50% NPK
T3	100% NPK	100% NPK
T4	150% NPK	150% NPK
T5	100% NPK + Zn @ 10 kg ha^{-1}	100% NPK
T6	100% RD of NP	100% RD of NP
T7	100% RD of N	100% RD of N
T8	100% NPK + FYM @ 5 t ha^{-1}	100% NPK
T9	50% NPK + BGA @ 10 kg ha^{-1} (dry culture)	50% NPK
T10	50% NPK + *in situ* green manuring of *dhaincha*	50% NPK

Organic manure	Nutrient content (%) on oven dry basis			Biomass addition on oven dry wt. basis (t ha^{-1})	N added (kg ha^{-1})
	N	P	K		
FYM	0.52	0.22	0.63	5.00	26
Dhaincha	2.87	0.32	1.12	4.13	119

Experiment was laid out in randomized completely block design (RBD) with four replications. Three soil samples were collected from surface (0-15 cm) and sub-surface (15-30 cm) layer at maximum tillering (40 DAT) and harvest of rice in 2014-15 after 16 years of continuous rice-wheat system. Soil samples were air-dried in shade, carefully and gently ground with the wooden pestle and mortar to break soil lumps (clods) and passed through 2-mm sieve. The sieved samples were mixed thoroughly and stored in polythene bags, properly labeled and preserved for subsequent analysis.

Total N in soil samples was determined by digestion of soil samples with sulphuric acid at a temperature between 360 and 410 ^{0}C in presence of K_2SO_4: $CuSO_4$ mixture followed by distillation. The ammonia liberated in the distillate was absorbed in boric acid and titrated against 0.005 *N* H_2SO_4 (Bremner 1965a). Inorganic (ammonium + nitrate)–N was determined by 2 *M* KCl extract as per the method given by Bremner (1965b).

Organic N fractions were determined in the soil hydrolysates (Bremner 1965c). Briefly, finely ground (<100 mesh) soil containing about 10 mg of N was placed in 125 mL Erlenmeyer flask fitted with a ground glass joint (24/40). Two drops of n-octyl alcohol and 20 mL of 6 *N* HCl were added and content of the flasks was swirled until the acid was thoroughly mixed with soil. The flask was then placed on an electric hot plate and flask was connected to a Liebig condenser. The soil-acid mixture was boiled gently under reflux for 12 h and the hydrolysates after neutralization were used for subsequent analysis. Total hydrolysable N (THN) was determined by digesting known volume soil hydrolysate followed by distillation after the addition of standard NaOH solution. The ammonia liberated in the distillate and absorbed in boric acid was titrated against standard solution of H_2SO_4. The non-hydrolysable N (NHN) was determined as difference between total soil N and total hydrolysable N and inorganic-N. Hydrolysable ammonium-N (HNH_4-N) in soil hydrolyasate was determined by micro-Kjeldahl distillation method. The amino acid-N (AAN) was determined by phosphate-borate buffer solutions and ninhydrin reagent. Amino sugar-N (ASN) was determined as the difference between the two forms of N.

Amino sugar-N (ASN) = (hydrolysable NH_4^+-N + hexose amine-N) - (hydrolysable NH_4^+-N).

Hydrolysable unknown-N (HUN) was taken as the difference between total hydrolysable N and the N accounted for as hydrolysable ammonium + amino acids + amino sugars-N.

The N recovery efficiency was computed from the following relationship.

$$\text{NRE (\%)} = \frac{\text{(N uptake in fertilized plot - N uptake in control plot)}}{\text{N applied (kg ha}^{-1}\text{)}} \times 100$$

To assess the relationship among rice grain yield and various N fractions a simple correlation was worked out. Contribution of each N fraction to rice grain yield and N uptake was determined by multiple regression analysis. The multiple step-wise regression analysis was worked out separately among forms of N along with rice grain yield and N uptake is given below.

$$y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6$$

where,

y = Dependent variables (rice grain yield and N uptake)

a = Constant

b_1, b_2……b_n represents regression coefficients.

X_1, X_1….X_n represents independent variables *viz*. Inorganic N, HNH_4^+-N, AAN, ASN, HUN and NHN

The data generated was subjected to statistical analysis. The data was tested for their level of significance at $P = 0.05$ as per Panse and Sukhatme (1971).

Results and Discussion

Nitrogen Fractions

Mineral N

The mineral N among various treatments ranged between 22.2 to 57.3 mg kg^{-1} (Table 2). The mineral N was increased significantly with the increasing levels of NPK alone or in combination with FYM. The application of 100% NPK along with FYM

Table 2. Effect of manurial and fertilizer treatments on N fractions in soil at maximum tillering and harvest of rice after 16 years of rice-wheat cropping

Treatments	Inorganic N (mg kg^{-1})	THN (mg kg^{-1})	NHN (mg kg^{-1})	HNH_4N (mg kg^{-1})	AAN (mg kg^{-1})	ASN (mg kg^{-1})	HUN (mg kg^{-1})	TN (mg kg^{-1})
Control	22.2^{a}	324^{a}	116^{a}	79^{a}	125^{a}	19.12^{a}	101	462^{a}
50% NPK	29.8^{b}	415^{b}	136^{bc}	106^{b}	158^{b}	23.41^{ab}	127	580^{b}
100% NPK	36.2^{c}	480^{c}	153^{cde}	122^{cd}	191^{c}	29.11^{cd}	137	669^{c}
150% NPK	47.7^{d}	540^{d}	158de	140^{e}	231^{d}	32.84^{d}	137	746^{d}
100% NPK + Zn	38.0^{c}	483^{c}	153^{cde}	123^{cd}	195^{c}	30.03^{cd}	136	675^{c}
100% NP	35.3^{c}	475^{c}	155de	120^{cd}	192^{c}	28.97^{cd}	134	666^{c}
100% N	35.0^{c}	471^{c}	158de	117^{c}	190^{c}	28.05b^{cd}	136	663^{c}
100% NPK + FYM	57.3^{e}	600^{e}	166^{e}	165^{f}	271^{e}	36.77^{de}	127	823^{e}
50% RDF + BGA	30.3^{b}	419^{b}	134^{b}	107^{b}	165^{b}	24.01^{b}	122	584^{b}
50% RDF + GM	47.7^{d}	468^{c}	143^{bcd}	129^{d}	194^{c}	27.19^{bc}	118	658^{c}
Mean								
LSD (P=0.005)	4.60	25.3	16.6	9.0	15.9	4.83	NS	30.5
Stages								
S1	44.1^{a}	499^{a}	152^{a}	128^{a}	197^{a}	30.41^{a}	143^{a}	694^{a}
S2	31.8^{b}	436^{b}	143^{b}	113^{b}	186^{b}	25.49^{b}	112^{b}	611^{b}
LSD (P=0.005)	1.50	13.47	NS	4.76	8.26	1.66	14.78	15.78
Depth								
D1	40.9^{a}	502^{a}	159^{a}	129^{a}	201^{a}	30.71^{a}	141^{a}	702^{a}
D2	35.0^{b}	433^{b}	135^{b}	112^{b}	181^{b}	25.18^{b}	114^{b}	603^{b}
LSD (P=0.005)	1.50	13.4	10.7	4.7	8.2	1.66	14.78	15.7

THN- Total hydrolysable N, NHN- Non-hydrolysable-N, HNH_4N- Hydrolysable ammonium-N, AAN- Amino acid-N, ASN- Amino sugar-N, HUN- Hydrolysable unknown N, TN-Total N significantly increased the mineral N (57.3 mg kg^{-1}). The treatments which comprised 100% N *viz*., 100% NPK + Zn, 100% NPK, 100% NP and 100% N were equally effective in improving the status of mineral N in soil. However, the magnitude of increase in mineral N was noted in the order of 50% NPK, 100% NPK and 150% NPK which could be attributed to the increasing order of fertilizer application. The mineral N was decreased significantly at harvest over tillering stage and decreased with increasing depth of soil. The increase in the mineral N content of soil with the combined application of manures and fertilizers might be due to higher accumulation of organic matter and its subsequent decomposition and mineralization which contributed in accumulating higher amount of N over suboptimal treatments (Basumatary and Talukdar 1998). Application of 50% NPK + GM also increased the content of mineral N (47.7 mg kg^{-1}) as compared to 50% NPK along with BGA because small quantity of BGA dry culture could not improve mineral N status of soil.

The decline in mineral N with depth may be due to application of fertilizers and manures in the surface layer and less movement to the lower layer. Singh and Singh (2007) also reported that various forms of N decreased with increase in soil depth except for the fixed NH_4^+-N, which increased with increase in depth in the eight soil profiles belonging to Alfisols, Inceptisols and Entisols of Uttarakhand. The decrease in inorganic N content of the surface and sub-surface soil from tillering to harvest stage might be due to its uptake by crop and losses of NO_3^--N through leaching. Muthuswamy *et al.* (1975) reported that NO_3^--N and NH_4^+-N contents increased with increasing levels of inorganic N, but declined with advancement of growth stages of rice.

The inorganic N content in unmanured control was quite low as compared to the combined use of chemical fertilizers and manure, indicating that only a small portion of the organic N is mineralized at a given point of time. Santhy *et al.* (1998) measured the highest NH_4^+-N and NO_3^--N in the plots with combined application of NPK and FYM, which was ascribed due to increased microbial activity and resultant in enhanced nitrification process and reduction in leaching losses.

Total Hydrolysable N

The organic N fraction *viz*., amino acid-N, hydrolysable NH_4^+-N, hydrolysable unknown-N and amino sugar-N increased significantly with the application 100% NPK + FYM over the other treatments (Table 2). The improvement in total hydrolysable N was generally observed in the treatments which received 100% N *i.e.* 100% NPK, 100% NPK + Zn, 100% NP and 100% N alone as compared to suboptimal dose of NPK. This is ascribed to the fact that most of the added urea-N was transformed into hydrolysable organic-N fractions. The results are in line with the earlier findings reported by Prieto *et al.* (1997). A significant increase in exchangeable NH_4^+-N and hydrolysable NH_4^+-N fractions with increasing levels of N applied either as chemical fertilizer alone or along with organic manure was also reported by Umesh *et al.* (2014). The improvement in total hydrolysable-N under 50% NPK + GM treatment is obvious, since GM-N released hydrolysable-N in soil on decomposition. On the other hand, continuous cropping without manures and fertilizers resulted in depletion of total hydrolysable N (Sammi Reddy *et al.* 2003).

Kher and Minhas (1992) stated that the total hydrolysable-N which accounted for 75.8 to 82.8% of the total N content of soil was constituted by 32.7% of amino acid-N and 30.4% of hydrolysable NH_4^+-N in the long-term fertilizer plots after 13 year of cropping on an acid soil of Palampur. Similarly, Manjunath (1999) reported that the soil profile of Northern Transition Zone of Karnataka contained total hydrolysable-N between 84.1 to 86.0% of total N out of which 36.0 to 48.8% was amino acid-N, 39.0 to 53.0% was amino sugar-N, hydrolysable NH_4^+-N ranged from 14.1 to 25.5%, unidentified N ranged from 13.0 to 56.0% and acid insoluble-N ranged from 47.0 to 58.0% of total N. The dominant fraction of organic-N was amino acid-N under intensive rice-wheat cropping sequence which contributed to the extent of 38.6 to 45.2% to total hydrolysable-N. The amino sugar-N was contributed very least to total hydrolysable-N. The total hydrolysable-N decreased with increase in soil depth and advancement in crop growth period. The decrease in hydrolysable-N fraction with increase in depth might have been associated with the intensity of mineralization, which reduced with lower depth. These observations are in accordance with those (Basumatary and Talukdar 1998).

Non-hydrolysable N

Various fertilizer treatments significantly influenced the non-hydrolysable-N (Table 2). The non-hydrolysable-N ranged between 116 to 166 mg kg^{-1} irrespective of crop stage and soil depth. Like other fractions, significantly higher values (166 mg kg^{-1}) of non-hydrolysable-N were recorded with the application of 100% NPK + FYM compared to all other treatments. The lowest values were observed under control (116 mg kg^{-1}) and 50% NPK (136 mg kg^{-1}) treatments. The treatments comprising 100% NPK, 100% NPK + Zn, 100% NP and 100% N contributing equally in improving the status of non-hydrolysable-N. Except amino acid-N, non-hydrolysable-N is the dominant N fraction which was increased with increasing doses of fertilizers and further improved with green manure incorporations (Umesh *et al.* 2014).

Unlike other N fractions, there was no significant difference in non-hydrolysable-N content between tillering and harvest stage of rice. It seems that under intensive rice-wheat cropping system non-hydrolysable-N is least susceptible to decomposition than hydrolysable-N fractions like amino acid-N, amino sugar-N and hydrolysable NH_4^+-N (Sammi Reddy *et al.* 2003). Significantly higher values of non-hydrolysable-N were observed in surface layer (0-15 cm) as compared to sub-surface layer.

Contribution of various forms of N to total N

The contribution of inorganic N to total N was 5 and 7% in control and 100% NPK + FYM treatments, respectively (Fig. 1). The contribution of total hydrolysable N to total N irrespective of control and 100% NPK + FYM treatments ranged between 71 to 73% (Fig. 1a and b). The contribution of total hydrolysable-N to total N was higher both in control and NPK + FYM treated plot followed by non-hydrolysable-N and inorganic N. The contribution of hydrolysable unknown N to total hydrolysable-N decreased with increase in the levels of fertilizers alone or in combination with organic manures (Fig. 2). Relatively more contribution of hydrolysable unknown N to total N was noted in control, whereas, least contribution of hydrolysable unknown N to total N was recorded in NPK + FYM treated plot.

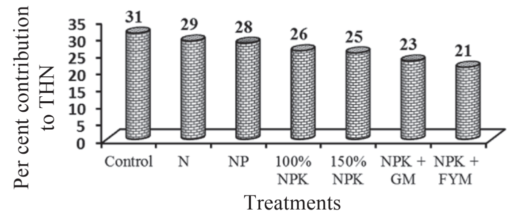

Fig. 2. Contribution of hydrolysable unknown N to total hydrolysable N

Yield and N uptake by rice

The treatment of 150% NPK and 100% NPK + FYM proved equally beneficial for getting higher yield of rice compared to other treatments (Table 3). The increasing levels of NPK significantly increased the grain yield of rice. Application of FYM along with 100% NPK did not cause significant increase in rice yield compared with 100% NPK alone. Similarly, application of BGA and GM at 50% NPK did not significantly increase the rice yield over 50% NPK alone. The yield obtained under 100% NPK + Zn was comparable to NPK alone treatments, suggesting no response of applied Zn, which might have associated with high level of DTPA-Zn status of soil. The

Table 3. Effect of nutrient management on yield of rice, nitrogen uptake and N recovery efficiency

Treatments	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	N recovery efficiency (%)
Control	2.50^{a}	45.1^{a}	-
50% NPK	5.29^{c}	79.9^{b}	69.5
100% NPK	5.88^{cd}	98.6^{d}	53.4
150% NPK	6.45^{d}	112.4^{e}	44.9
100% NPK + Zn	5.76^{cd}	104.3^{de}	59.2
100% NP	5.76^{cd}	98.7^{d}	53.6
100% N	4.16^{b}	78.5^{b}	33.3
100% NPK + FYM	6.44^{d}	113.5^{e}	54.7
50% NPK + BGA	5.03^{bc}	86.0^{bc}	81.8
50% NPK + GM	5.74^{cd}	92.6^{cd}	79.0
LSD (P=0.005)	0.90	12.52	—

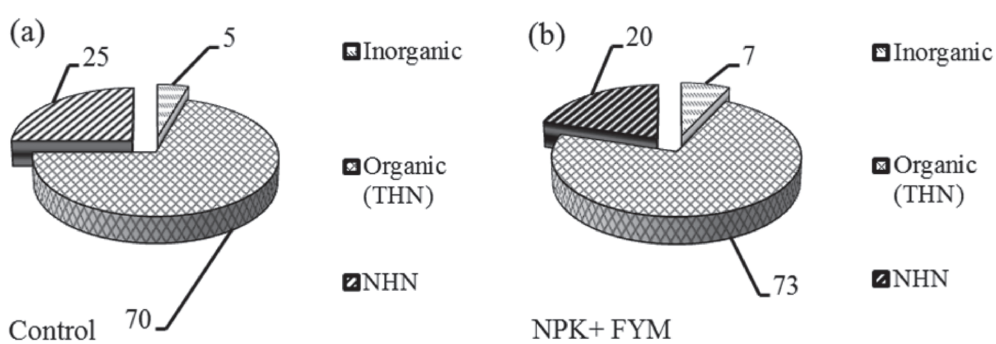

Fig. 1. Contribution of inorganic, organic and non-hydrolysable-N to total -N in control (a) and NPK + FYM (b)

combined application of manure and fertilizers considerably increased the grain yield of rice, as FYM in combination with fertilizers regulated the supply of nutrients in plants. Similar results in respect of yield of rice with integrated use of chemical fertilizers and organic manures were reported by Sood *et al.* (2008) under long-term fertilizer experiment on maize-potato-wheat sequence at Palampur. These results corroborate the earlier findings of Prasad and Sinha (2000).

Nutrient recovery efficiency (NRE) for N

The N recovery efficiency (NRE) was higher with sub-optimal dose of fertilizers which ranged between 69.5 to 81.8% followed by 100% NPK alone or in combination with FYM (Table 3). The balanced use of fertilizers (100% NPK) recorded NRE to the extent of 53.3% compared with higher dose of fertilizer (150% NPK) which registered NRE of 44.9%. The N use efficiency generally decreases with increase in fertilize dose. While application of P along with N caused significant improvement in NRE over 100% N, K application showed no additional beneficial effect. The higher NRE and partial factor productivity with optimized N management were also reported by Peng *et al*. (2013). Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of applied N fertilizers. The application of 100% NPK + FYM significantly increased the uptake of N (113.5 kg ha^{-1}). The increasing levels of fertilizers significantly increased the uptake of N by rice which justify the fact that necessity of relatively higher dose of balanced fertilizers.

Correlation among yield and various N fractions

Rice grain yield was positively and significantly correlated with all the N fractions excepts that for non-hydrolysable-N (Table 4). The non-hydrolysable-N did not have significant correlation with grain yield of rice at maximum tillering, but at harvest stage it showed positive and significant correlation with grain yield of rice. Umesh *et al.* (2014) showed a positive and significant correlation of non-hydrolysable-N with sugarcane yield. Between the two stages, rice grain yield was highly correlated with various N fractions at tillering compared to harvest stage. Similarly, grain yield of rice was better correlated with various fractions of N at 0-15 cm depth in comparison with 15-30 cm depth. Among the hydrolysable-N fraction, the hydrolysable NH_4^+-N and amino acid-N fractions was found to be the most important N fraction with respect to rice grain yield.

Table 4. Correlation coefficients (r) between rice grain yield and N fractions at tillering and harvest of rice

Form of N	Tillering stage		Harvest stage	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Inorganic-N	0.687**	0.618**	0.553**	0.604**
Amino acid-N	0.664**	0.626**	0.588**	0.568**
Amino sugar-N	0.554**	0.488**	0.445**	0.445**
Hydrolysable NH_4-N	0.698**	0.635**	0.610**	0.593**
Hydrolysable unknown N	0.551**	0.496**	0.489**	0.478**
Total hydrolysable-N	0.700**	0.666**	0.693**	0.635**
Non hydrolysable-N	0.276 NS	0.298 NS	0.378*	0.244NS
Total N	0.710**	0.663**	0.707**	0.641**

**Significant at 1% (*P=0.01*) probability level,*Significant at 1% (*P=0.05*) probability level, NS-non significant, n=40

Correlation among mineral N and various N fractions

The inorganic N fraction was found to be significantly and positively correlated with all the forms of N, except that non-hydrolysable-N at both depths as well as crop stages (Table 5). The total N (r = 0.791**), hydrolysable NH_4^+-N (r = 0.757**) and (r = 0.787**) and total hydrolysable-N (r = 0.749**) are the dominant N fractions were significantly and positively correlated with inorganic N fractions. This implies that, the dominant N fractions are the potential contributor towards plant available N (Kaur and Singh 2014). However, the non-hydrolysable-N did not have significant influence on inorganic N indicating that it is that portion of N which is available to rice plants slowly. The contribution of non-hydrolysable-N to total N was relatively less in NPK + FYM treatment (20%), whereas, its contribution was increased to 25% in control plot. Among the total hydrolysable-N fraction (amino acid-N, amino sugar-N, hydrolysable

Table 5. Correlation coefficients (r) between mineral N and N fractions

Nitrogen fractions	Mineral–N			
	Tillering stage		Harvest stage	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Amino acid-N	0.740**	0.736**	0.747**	0.741**
Amino sugar-N	0.582**	0.534**	0.547**	0.503**
Hydrolysable NH_4-N	0.785**	0.757**	0.787**	0.721**
Hydrolysable unknown N	0.598**	0.586**	0.472**	0.468**
Total hydrolysable-N	0.775**	0.695**	0.764**	0.749**
Non hydrolysable-N	0.310 NS	0.264 NS	0.138 NS	0.241 NS
Total N	0.791**	0.734**	0.777**	0.738**

**Significant at 1% (*P=0.01*) probability level,*Significant at 1% (*P=0.05*) probability level, NS-non significant, n=40

Table 6. Step-wise multiple regression analysis of dependant variables (rice grain yield and N uptake) and independent variables (forms of N)

"Y" variables	Variables on which "Y" is regressed	Multiple regression equation	R^2
Rice grain yield	$X_1+X_2+X_3+X_4+X_5+X_6$	y = -6.87 – 0.109 (X_1) + 0.337 (X_2) + 0.036 (X_3) + 0.048 (X_4) + 0.095 (X_5) + 0.008 (X_6)	0.580*
	$X_1+X_2+X_3+X_4+X_5$	y = -6.321- 0.122(X_1) + 0.345 (X_2) + 0.037 (X_3) + 0.041 (X_4) + 0.096 (X_5)	0.579*
	$X_1+X_2+X_3+X_5$	y = -6.121 -0.124 (X_1) + 0.347 (X_2) + 0.041 (X_3) + 0.097 (X_5)	0.579*
	$X_2+X_3+X_5$	y = -3.895 + 0.321 (X_2) + 0.028 (X_3) + 0.090 (X_5)	0.575*
	X_2+X_5	y = -3.945 + 0.357 (X_2) + 0.099 (X_5)	0.571*
N uptake by rice	$X_1+X_2+X_3+X_4+X_5+X_6$	y = -20.88 + 0.132 (X_1) + 0.451 (X_2) + 0.024 (X_3) + 0.265 (X_4) + 0.178 (X_5) + 0.107 (X_6)	0.663*
	$X_1+X_2+X_4+X_5+X_6$	y = -21.004 + 0.165 (X_1) + 0.462 (X_2) + 0.316 (X_4) + 0.181 (X_5) + 0.111 (X_6)	0.662*
	$X_2+X_4+X_5+X_6$	y = -22.45 +0.525 (X_2) + 0.324 (X_4) + 0.195 (X_5) + 0.093 (X_6)	0.659*
	$X_2+X_5+X_6$	y = -20.02 + 0.574 (X_2) + 0.206 (X_5) + 0.086 (X_6)	0.654*
	X_2+X_5	y = -12.16 + 0.619 (X_2) + 0.210 (X_5)	0.644*

*Significant at *P=0.05*, **Significant at *P=0.01*

X_1, X_2, X_3, X_4, X_5 and X_6 represent independent variables *viz*. Inorganic N, HNH_4- N, AAN, ASN, HUN and NHN on which "Y" is regressed.

NH_4^+-N and hydrolysable unknown N), the hydrolysable NH_4^+-N and amino acid-N fractions have been recognized to be the most important N fraction with respect to mineral N (Tabassum *et al.* 2010). Study by Gotoh *et al.* (1986) revealed that best correlation to mineralized N was for amino acid-N (r = 0.983) and less significant was for non-hydrolysable-N (r = 0.918).

Multiple stepwise regression among yield, N uptake and various N fractions

The relative contribution of N fractions to rice grain yield and N uptake was worked out by stepwise multiple regression analysis (Table 6). Regression analysis indicated that hydrolysable NH_4^+-N and hydrolysable unknown N accounted for 57.1% of the total variation in rice grain yield. Inclusion of other N fractions did not improve the contribution towards rice grain yield. It indicates that the hydrolysable NH_4^+-N and hydrolysable unknown N fractions are the dominant N fractions contributing towards increase in rice yields.

Like grain yield, total N uptake by rice showed significant and positive relationship with the inclusion of various forms of N (Table 6). Among the organic N fractions, hydrolysable NH_4^+-N and hydrolysable unknown N forms the dominant N fractions, contributed to the extent of 64.4% to the N uptake by rice. From a long-term fertilizer experiment, Santhy *et al.* (1998) reported that amino acid and hydrolysable NH_4^+-N were the dominant fractions influencing total N uptake by rice. In the present study, the contribution of amino acid-N to the total hydrolysable-N was substantial; however, the same has not been reflected in the rice grain yield and N uptake.

Conclusions

On the basis of foregoing results, it can be concluded that integrated use of fertilizers and FYM significantly increased the inorganic and organic N fractions. The N recovery efficiency was higher in 50% NPK along with blue green algae or along with green manuring. Different N fractions significantly and positively correlated with rice grain yield. The step-wise multiple regressions indicated that hydrolysable ammonium and hydrolysable unknown N formed the dominant N fraction, and contributed substantially to rice grain yield.

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