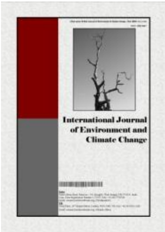

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Sub-soil Nitrogen Content as Influenced by Long-term Manuring and Its Relationship with Nitrogen Availability and Productivity of a Rice-rice Cropping System in Eastern India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Investigation was made to study the impact of long-term fertilizer and manure application on the sub-soil nitrogen (N) fertility of an acidic *Inceptisol* under continuous rice-rice cropping system. For this purpose, a long-term fertilizer experiment commenced from 2005-06, *rabi* season in the Central Farm of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar under aegis of ICAR, New Delhi was used. The experiment had 12 manurial treatments whose impact on sub-soil N fertility up to 75 cm depth and its relation with surface soil N fertility was studied. N uptake and crop yield has been assessed after 20 cropping cycles. The initial soil was acidic (pH 5.8) with low soil organic carbon (4.3 g kg $^{-1}$) and CEC of 3.75 cmol (p^+) kg^{-1}, mineralizable N of 187 kg ha^{-1} and total N of 1280 kg ha^{-1}. After 20 cropping cycles, the soil organic carbon (SOC) content increased in all the fertilized treatments in the surface layer and with depth it decreased sharply from 15-30 cm to 30-45 cm layer. Treatments with balanced nutrition registered higher content of total N, organic

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N, mineralizable N and inorganic N both in surface soil and sub-soil. Not only the surface soil but also the sub-soil contents of total N, organic N and mineralizable N are significantly influenced by long-term use of fertilizer nutrients and manure under wet land intensive rice production system. Sub-soil contents of total N, organic N, mineralizable N, inorganic N, ammonium N and nitrate N have strong positive correlation with those of surface layer. SOC, total N, mineralizable N and inorganic N are strongly correlated with each other in the same layer. Correlation of organic N and total N with nitrate N was however, significant up to 30 cm depth and beyond that there was no correlation at 30-45 cm layer. From the results, it is concluded that application of nutrient in balanced and integrated manner (NPK + FYM) not only increased grain yield and sustainability of rice but also improved various pools of N in surface as well as sub-soil up to 75 cm depth of a wet land rice-rice production system under subtropical climatic situation.

Keywords: Long-term manuring; rice-rice system; sub-soil nitrogen; productivity; sustainability.

1. INTRODUCTION

Rice-rice production system is no longer productive in South East Asia [1] and nitrogen (N) is the one of most limiting nutrients for rice production under such system. Rice crop requires large amount of N for its growth, development and grain production. Generally, rice plant removes around 14-20 kg N to produce one tonne of rough rice including straw [2]. The amount of plant mineralizable N is positively influenced by N fertilization, mineralization of soil organic matter, biological N fixation and by precipitation. Negative influences result from immobilization, crop uptake and removal, denitrification (and to some extent nitrification), volatilization, leaching, run-off and erosion [3]. The relative importance of these processes depends on environmental variables such as soil pH, top soil texture, soil profile characteristics, soil aeration, water supply and temperature, as well as human activities such as type, amount, placement and timing of N fertilizers, crop residue management, tillage, soil compaction, drainage, irrigation and land use change.

Soil nitrogen status is one of the key parameters to assess the fertility status of soil. In most soils, N is predominantly organic in nature and only a small portion of total N is present in inorganic form. Soil organic N is the largest source of plant mineralizable N for rice representing 50 to 80% of total N assimilated by crop [4]. Soil organic N (SON) plays a key role in terms of plant nutrition through direct and indirect effects on microbial activity and nutrient availability [5]. Continuous N input increases soil total nitrogen (STN) content in the profile. Significantly higher total N content was reported in the surface soil with organic or organic–inorganic combined fertilization [6]. Continuous cropping and long-term nutrient management have influence on carbon and nitrogen content of soil of different layers and its availability to crops [7]. So far studies on relationship of soil nitrogen with crop yield are restricted to surface soil or maximum up to 30-45 cm depth. Lower layers of greater depth may also influence the surface soil nitrogen fertility and crop yield as there exists connectivity of layers because of submergence, linkage through leaching and percolation, capillary rise of soil solution, presence of oxidised and reduced zones at different layers under rice-rice system. No studies have yet been done on the content of various mineralizable pools of nitrogen in lower layers up to 75 cm or more and their relationship with upper surface soil nitrogen fertility, crop yield and sustainability. So, this investigation was conducted using 10-year-old long-term fertilizer experiment (ICAR, New Delhi) in order to get more information on the impact of repeated use of various inorganic fertilizer nutrients and organic manure on contents N of various mineralizable forms of nitrogen in sub-soil up to 75 cm and study their relationship with the contents of surface soil and crop productivity.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted during *kharif*, 2015 and *rabi*, 2015-16 in the ongoing experimental field of All India Coordinated Research Project (AICRP) on Long-Term Fertilizer Experiment (LTFE) of ICAR at OUAT, Bhubaneswar, India (20°17′ N, 85°49′ E and 30 m above mean sea level). The location of the experimental site is characterized as sub-humid sub-tropical climate with *rabi* season from October to June and *kharif* season from July to September. The average annual rain fall is 1453 mm and the mean maximum and minimum temperatures are 31.40^{o} C and 21.10^{o} C, respectively. The experimental soil is a pale yellow (10YR6/8), lateritic *Inceptisols*. The initial soil properties of 0-15cm layer were sandy loam texture with clay 17%, silt 12% and sand 71%, bulk density 1.55 kg m^{-3}, cation exchange capacity 3.75 cmol (p^+) kg^{-1}, pH 5.8, electrical conductivity 0.12 dSm^{-1}, organic carbon 4.3 g kg^{-1}, mineralizable N (Alkaline $KMnO_4$)187, available P (Olsen's)19.4 and available K (NH_4OAc) 43.4 kg ha^{-1}, respectively. The DTPA extractable Fe, Mn, Zn and Cu were 33.0, 7.53, 1.80 and 3.15 mg kg^{-1}, respectively. Exchangeable cations Ca and Mg were 2.25cmol (p^+) $kg^{-1}$and 0.65cmol (p^+) kg^{-1}. The hot water-soluble boron was 0.46 mg kg^{-1}.

2.2 Experiment Details

The experiment consisted of 12 treatments; T_1-100% PK, T_2 - 100% NPK, T_3- 150%NPK, T_4-100%NPK+Zn, T_5-100%NPK+ FYM, T_6-100%NPK+Lime+FYM, T_7-100%NPK+B+Zn, T_8-100%NPK+S+Zn, T_9-100%N, T_{10}-100%NP, T_{11}-100%NPK+Lime and T_{12}- Control, where 100% NPK correspond to 80-40-60 kg of N, P_2O_5 and K_2O ha^{-1}. The experiment was laid out in randomized block design (RBD) with four replications. Rice cultivar Swarna (MTU 7029) was grown in *kharif* season and Lalat in *rabi* season of every year. Twenty-five days old rice seedlings were transplanted at a spacing of 20 cm × 10 cm with 2-3 seedlings per hill to puddled field in both the seasons. Nitrogen (N) was applied in three splits i.e. 25% at puddling as basal, 50% topdressing at 18 days after transplanting and 25% top dressed at panicle initiation stage. Entire dose of phosphorus (P) was applied during puddling as basal and potassium (K) was applied in two splits, 50% at puddling as basal and 50% topdressing at panicle initiation (PI) stage. Entire FYM (5 t $ha^{-1}$$season^{-1}$) was applied at the time of puddling. FYM has been added @ 5 t ha^{-1} in each season in T_5 and T_6. Lime @ 1 t ha^{-1} in each season has been applied in T_6 and T_{11} at the time of land preparation. Zn has been applied as Zinc oxide 0.4% solution seedling root dipping in T_4, T_7 and T_8. Borax was foliar sprayed twice as a source of boron @0.25% solution in T_7. Gypsum was applied to supply sulphur @ 30 kg ha^{-1} in T_8. Necessary uniform intercultural, water management and plant protection measures were undertaken in general until the crop was matured for harvesting. Before harvest of crop, grain yield was monitored through crop cutting.

2.3 Soil Sample and Plant Analysis

Individual soil samples from each plot were collected from surface downwards up to 75 cm depth at an interval of 15 cm i.e.,0-15, 15-30, 30-45, 45-60 and 60-75 cm after harvest of *kharif* rice crop in the year 2015 through profile digging. Immediately after collection, the soil samples were air dried, ground and passed through a 2 mm sieve and analysed for different basic soil properties by following standard laboratory procedures. Different forms of N *viz.*, NO_3^--N, NH_4^+-N, mineralizable N and total -N in soil samples were estimated adopting methods suggested by [8]. Plant samples after separating straw and grain were washed thoroughly, air dried and then oven dried at 60°C, finely pulverized and digested in a diacid mixture of HNO_3 and $HClO_4$ in 3:1 ratio. Nitrogen was determined by modified micro-Kjeldahl method [9]. Organic carbon (OC) in soil was determined by a wet oxidation procedure of [10].

2.4 Statistical Analysis

The experiment was laid out in Randomized Complete Block Design with 12 treatments and 4 replications. Analysis of variance has been conducted to test the overall significance of difference between the treatments.

Null hypothesis, H_0: all the treatment means are identical.

Alternate Hypothesis, H_1: at least one pair of treatment mean differs significantly.

Test statistics for the treatment, $F=\frac{TMS}{EMS}$

If the p value of F is <0.05, then F is considered to be significant and H_0 is rejected.

If F is found to be significant, then Least Significance Difference (LSD) test is conducted (at α=0.05) to test the significance of difference between each pair of treatment [11].

Simple linear regression analysis of was carried out between yield and sustainability with basic soil properties using the data analysis tool of MS Excel.

3. RESULTS AND DISCUSSION

3.1 Soil Organic Carbon

Application of various combination of inorganic fertilizer nutrients at varying levels or in

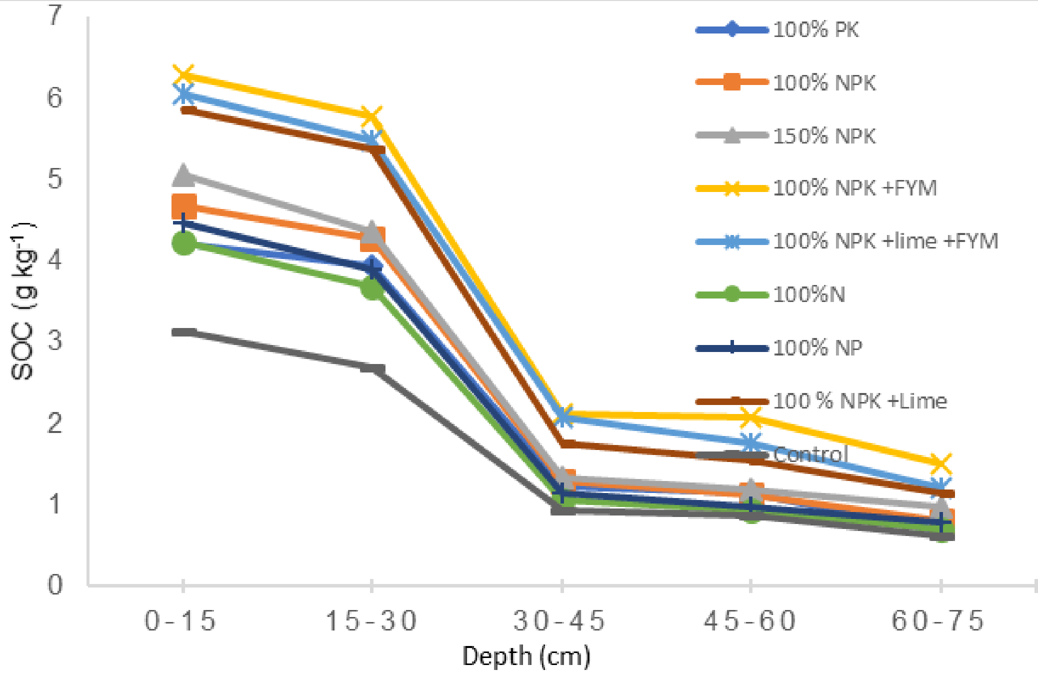

Fig. 1. Effect of long-term manurial practices on SOC at different depths under rice-rice intensive cropping system

combination with FYM had significant influence on soil organic carbon content after continuous rice-rice cropping system for 10 years (Table 1). In the surface soil it varied from 3.12 to 6.29 g kg^{-1}. Non-application of fertilizer/FYM significantly decreased soil organic carbon content in control both in the surface and sub-surface soil layers, whereas, substantial build-up in the organic carbon content occurred under NPK+FYM, NPK+lime+FYM and NPK+lime treatments. The increase in SOC content under integrated use of fertilizers and organic manure treatments might have been due to direct incorporation of organic matter, better root growth and more plant residue addition resulting in increased soil organic carbon content. These results are in conformity with the finding of Singh et al. [12], Jadhao et al. [13], Ravankar et al. [14] and Mishra et al. [15] who reported the enhanced soil organic carbon status after ten years of continuous rice-wheat cropping under varying fertilizer and manure treatment in *Mollisols* at Pantnagar. The maximum increase in soil organic carbon content was observed with integrated use of inorganic fertilizers (N+P+K) and organic manure in rice-wheat cropping system in long-term experiment [16]. With depth the content decreased slightly up to second layer & sharply in the third layer (Fig. 1).

3.2 Total Nitrogen

Total N content in soil as influenced by various treatments (Table 1) indicated that higher values of N content was obtained from surface soil which could be due to the presence of residues after the harvest of crop as suggested by Kushwaha et al. [17] and Singh et al. [18]. Further, lowest content found in unfertilized control (676.4, 543.4, 435.7, 221.6 and 110.2 kg ha^{-1}, respectively under 0-15, 15-30, 30-45, 45-60 and 60-75 cm depths) is attributed to less productivity as a result of no fertilizer application because organic matter and biological fixation are the sources of N addition and both are dependent on primary productivity [18]. The total N content ranged from 676.4 to 1712.4 kg ha^{-1} in surface soil and 110.2 to 1277.6 kg ha^{-1} in sub-surface soil. Increase in total N was noted with concomitant increase in fertilizer levels from N alone (100% N) to optimal (100% NPK) and further to super optimal (150% NPK) level, which again due to increase in primary productivity [19]. The highest total N content was registered with 100% NPK+FYM (1712.4 kg ha^{-1}) treatment followed by 100% NPK + lime + FYM (1691.3 kg ha^{-1}) in the surface soil. The larger increase in total N in these plots was due to addition of extra N through FYM and greater amount of biomass

Table 1. Soil organic carbon (g kg^{-1}), total N (kg ha^{-1}) and organic N (kg ha^{-1}) in surface and sub surface soils under different treatments as influenced by long-term manurial practices

Treatments	SOC (g kg^{-1})					Total N (kg ha^{-1})					Organic N (kg ha^{-1})				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
100% PK	4.20	3.93	1.22	1.13	0.68	1019.6	812.5	523.5	240.8	122.7	952.4	786.8	502.3	227.1	114.7
100% NPK	4.67	4.27	1.28	1.11	0.80	1300.3	933.5	623.5	343.8	233.6	1218.2	904.8	601.2	329.9	225.4
150% NPK	5.05	4.35	1.32	1.18	0.98	1562.8	1235.8	986.7	565.8	207.7	1466.7	1203.3	964.0	552.0	199.1
100% NPK + Zn	4.92	4.52	1.49	1.19	0.85	1212.5	945.1	743.2	444.9	224.5	1124.2	912.8	721.4	431.1	216.1
100% NPK +FYM	6.29	5.77	2.12	2.08	1.50	1712.4	1277.6	945.8	589.6	366.3	1593.6	1221.9	912.4	570.4	354.5
100% NPK +lime +FYM	6.05	5.47	2.07	1.76	1.21	1691.3	1232.6	908.7	587.3	346.7	1579.8	1177.6	877.5	569.1	335.6
100% NPK +B +Zn	4.97	4.54	1.56	1.23	0.87	1377.5	965.3	713.6	388.5	292.6	1289.9	936.9	693.4	375.8	284.5
100% NPK S+ Zn	5.21	4.83	1.70	1.56	1.02	1408.6	1076.6	856.3	376.2	235.9	1320.5	1042.5	831.7	361.3	227.8
100%N	4.22	3.67	1.06	0.92	0.70	1011.2	850.6	712.5	322.5	145.8	936.6	826.7	692.9	311.2	138.5
100% NP	4.47	3.89	1.14	0.98	0.77	1057.1	876.8	744.2	334.6	154.5	980.3	849.6	724.7	322.8	147.1
100% NPK +Lime	5.86	5.38	1.76	1.55	1.15	1415.7	1120.6	854.8	434.6	251.5	1331.1	1078.9	828.5	420.4	242.4
Control	3.12	2.69	0.92	0.86	0.62	676.4	543.4	435.7	221.6	110.2	623.2	524.6	421.1	212.0	104.0
CD $_{(0.05)}$	0.57	0.48	0.20	0.17	0.11	49.3	39.4	32.3	27.8	21.3	49.5	39.1	32.6	28.1	21.2

to soil. Total soil N was also found to enhance in the treatment of INM (100% NPK + FYM), which is useful for N management under intensified rice -rice cropping in the subsequent years for better supply of N to the crops after its mineralization [20].

Similar to soil organic C content, the total N content was higher in surface soil as compared to subsurface soil. Continuous cropping without fertilization and manuring also resulted in depletion of total nitrogen both in surface and sub-soil.

3.3 Organic N

Data on organic N presented in Table 1 revealed that it varied from 623.2 kg ha^{-1} to 1593.6 kg ha^{-1} in surface soil and 104.0 kg ha^{-1} (60-75 cm) to 1221.9 (15-30 cm) kg ha^{-1} in sub-soil. Organic carbon contributed 92.1 to 97.7% of total N. In control it constituted 92.1% on the surface layer, 96.5% in 15-30 cm, 96.6% in 30-45 cm, 95.7% in 45-60 cm and 94.4% at 60-75 cm layer. Highest organic N was recorded in high yielding NPK+FYM treatment where it constitutes 93.1, 95.6, 96.5, 96.7 and 96.8% at the respective surface and sub-soil layers. The content almost reduced to half in 30-45 cm layer and then there was a sharp fall with the depth.

3.4 Mineralizable N

Mineralizable N is easily oxidizable N from organic matter. The initial (2005) mineralizable N value of the soil (0-15 cm) was 187.0 kg ha^{-1}. Improvement in mineralizable N values in both surface and sub-surface soil layers was noted in all the treatments (Table 2).

The mineralizable N content ranged from 154.4 to 291.3 kg ha^{-1} in surface soil and from 8.2 (60-75 cm) to 119.3 (15-30 cm) kg ha^{-1} in sub-surface soil. Increase in mineralizable N indicates that increase in easily oxidizable fraction of organic matter which means increase in availability of N to plant [17]. However, due to addition of fertilizer doses from 100% to 150%, N content was correspondingly improved indicating an impact of fertilizer application on enrichment of N pools [18]. The highest mineralizable N content registered in 100% NPK+FYM (291.3 kg ha^{-1}) treatment followed by 100% NPK +lime +FYM (275.5 kg ha^{-1}) could be resulted due to addition of larger amount N by paddy root and stubble biomass as well as addition of extra N through FYM each year and a part of it contributed to total N [21]. Cropping without any nutrient input led to perceptible decline in soil mineralizable N from the initial N content due to more removal of N through biomass and less root and stubble addition. In relation to the initial status, the mineralizable N declined by 21.1% in surface soils with continuous cropping in the control plot. Relatively low content of mineralizable N in sub-surface layer is due to less incorporation of biomass and poor biological activities [5].

3.5 Inorganic N

Inorganic N content presented in the Table 2 indicated similar trend as total N. The inorganic N (NH_4^+-N+NO_3^--N) content of soil was significantly higher at 0-15 cm depth as compared to that at 15-30 cm depth, which could be due to the presence of crop residues, FYM, more microbial activity and inorganic fertilizers in the surface layer [22]. The inorganic N content varied from 53.2 to 118.8 kg ha^{-1} in surface soil and from 6.2 (60-75 cm) to 55.7 (15-30 cm) kg ha^{-1} in sub-surface soil layer. The addition of different doses of fertilizers and FYM contributed towards relative increase in inorganic N content in surface and sub-surface layers. Similar, findings were reported by Khandagle et al. [23]. The highest inorganic N content was recorded in 100% NPK+FYM (118.8 kg ha^{-1}) treatment followed by 100% NPK+lime+FYM (111.5 kg ha^{-1}) and the lowest inorganic N content was obtained in control plot (53.2 kg ha^{-1}) without fertilizer application, which directly or indirectly affected the plant growth. Increase in inorganic fraction of N is due to increase in organic carbon in soil which provided more energy source to microbes and also more site for the retention of NH_4^+–N as well NO_3^--N which were replaceable with KCl [17]. Majhi et al. [24] reported application of NPK+FYM improved soil fertility by stimulating microbial activity, improving soil physical health, resisting drop in pH to more acidity & improving CEC and macro and micronutrients level. Further, lowest content was found in control (53.2 kg ha^{-1}) which directly or indirectly affected normal biological activities.

The content of NH_4^+ - N was recorded highest under NPK + FYM (80.9 kg ha^{-1}) after 20^{th} cropping cycle (Table 3). It ranged from 38.4 to 80.9 kg ha^{-1}in the surface soil and its content decreased with depth up to 75 cm.

Table 2. Inorganic N (kg ha^{-1}) and mineralizable N (kg ha^{-1}) in surface and sub surface soils under different treatments as influenced by long-term manurial practices

Treatments	Inorganic (NH_4^+-N+NO_3^--N) N (kg ha^{-1})					Mineralizable N (kg ha^{-1})				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
100% PK	67.2	25.7	21.2	13.7	8	180.8	61.1	29.2	18.8	10.6
100% NPK	82.1	28.7	22.3	13.9	8.2	220.4	64.5	30.2	19.5	11.2
150% NPK	96.1	32.5	22.7	13.8	8.6	257.6	75.7	33.2	20.4	12.2
100% NPK + Zn	88.2	32.3	21.8	13.8	8.4	235.7	75.6	33.8	20.1	12.0
100% NPK +FYM	118.8	55.7	33.4	19.2	11.8	291.3	119.3	50.7	25.5	15.6
100% NPK +lime +FYM	111.5	54.9	31.2	18.2	11.1	275.5	116.3	40.1	22.9	14.6
100% NPK +B +Zn	87.6	28.4	20.2	12.7	8.1	238.3	70.1	30.2	18.6	11.5
100% NPK S+ Zn	88.1	34.1	24.6	14.9	8.1	232.8	76.9	35.2	21.3	12.7
100%N	74.5	23.9	19.6	11.3	7.3	205.1	55.1	28.2	17.9	10.9
100% NP	76.8	27.2	19.5	11.8	7.4	215.2	64.8	29.2	17.8	10.6
100% NPK +Lime	84.6	41.7	26.3	14.2	9.1	217.9	92.7	35.6	21.3	12.9
Control	53.2	18.9	14.6	9.6	6.2	154.4	49.1	25.3	15.6	8.2
CD $_{(0.05)}$	3.4	2.5	1.8	1.2	0.8	11.1	7.2	4.3	2.8	1.8

Table 3. NH_4^+-N (kg ha^{-1}) and NO_3^-- N (kg ha^{-1}) in surface and sub surface soils under different treatments as influenced by long-term manurial practices

Treatments	NH_4^+-N (kg ha^{-1})					NO_3^-N (kg ha^{-1})				
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
100% PK	47.2	17.2	12.9	8.4	4.9	20	8.5	8.3	5.3	3.1
100% NPK	57.6	19.4	15.3	9.8	5.9	24.5	9.3	7	4.1	2.3
150% NPK	65.9	23.4	16.8	9.9	6.3	30.2	9.1	5.9	3.9	2.3
100% NPK + Zn	56.3	20.7	13.0	9.1	5.9	31.9	11.6	8.8	4.7	2.5
100% NPK +FYM	80.9	37.9	23.9	13.1	7.8	37.9	17.8	9.5	6.1	4
100% NPK +lime +FYM	73.7	37.7	21.3	11.8	7.3	37.8	17.2	9.9	6.4	3.8
100% NPK +B +Zn	56.7	19.2	12.8	8.5	5.5	30.9	9.2	7.4	4.2	2.6
100% NPK S+ Zn	53.5	21.4	15.2	9.5	5.1	34.6	12.7	9.4	5.4	3
100%N	44.7	13.6	12.4	6.4	4.2	29.8	10.3	7.2	4.9	3.1
100% NP	51.6	16.9	13.1	8.2	5.2	25.2	10.3	6.4	3.6	2.2
100% NPK +Lime	56.7	30.1	18.4	9.7	6.6	27.9	11.6	7.9	4.5	2.5
Control	38.4	12.2	10.8	7.4	4.8	14.8	6.7	3.8	2.2	1.4
CD $_{(0.05)}$	2.2	1.8	1.6	1.2	1.1	1.8	1.0	0.75	0.70	0.62

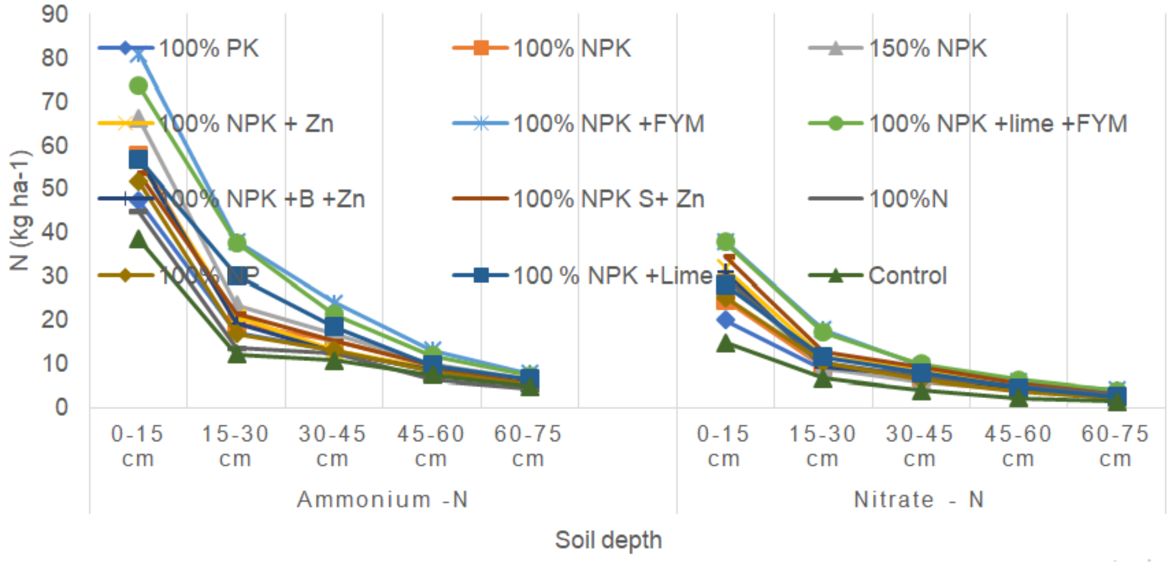

Fig. 2. Distribution of NH_4^+ - N and NO_3^- -N at different depths as influenced by long-term manurial practices

Mineralization of FYM released appreciable amounts of ammonical N, which could contribute to exchangeable NH_4^+ -N [25]. As the organic carbon content is directly related with CEC, the N released through mineralization of organic matter and inorganic fertilizers applied could be retained in the exchange sites. Combined application of NPK + FYM also ensured higher NO_3^- -N (37.9 kg ha^{-1}) than control (14.8 kg ha^{-1}) which could be due to increased microbial activity and resultant enhanced nitrification process with a concomitant reduction in leaching losses (Fig. 2). Increase in the rate of inorganic N added also enhanced the NO_3^--N content possibly due to the conversion of applied mineral N via nitrification process. The NO_3^- -N content varied from 1.4 to 17.8 kg ha^{-1} in the sub-soil and the lowest was recorded at 60-75 cm layer. The drop in NO_3^- -N was more sharp up to 45 cm than the deeper layers beyond 45 cm where it was almost constant.

3.6 Correlation among Various Pools of N and SOC of Different Layers

Soil organic carbon of all the layers strongly correlated with total N, mineralizable N, inorganic N, ammonium N and nitrate N of respective layers (Table 4). Among various N pools there was strong correlation of organic N with total N, mineralizable N, inorganic N and ammonium N of respective layers. Total N also had strong positive correlation with inorganic N and ammonium N of all the layers. Correlation of organic N and total N with nitrate N was however significant up to 30 cm depth and beyond that there was no correlation at 30-45 cm layer (r= 0.511 & 0.524).

3.7 Correlation of Contents of Various Nitrogen Pools of Bottom Layers with those of Surface Layer

It was also observed that the correlation of lower layers with surface layer in different fractions of N was found positively significant. The r value in the Table 5 indicated that the correlation between SOC of surface layer with lower layers was highly significant (r=0.997**, 0.958**, 0.933** and 0.949**). Depending on type of soil, cropping system and agronomic management practices and type of nutrient, the relationship of contents of N of surface layer with that of bottom layers may differ. Under wet land rice-rice production system, correlation of lower layer contents with upper layer has been worked out. All the form of N, such as total N, inorganic N, mineralizable N in lower had strong relationship on that of surface layer.

3.8 Grain Yield and Nitrogen Uptake

The fertilizer treatments comprising fertilizer alone or combination with FYM/soil amendment had significant effect on grain yield of rice (Table 6) in *kharif* season. Perusal of results in grain yield revealed that there was a significant variation among the treatments. The highest grain yield was recorded in the treatment,

Table 4. Correlation coefficients (r) between different nitrogen fractions and SOC at different depths

			Total N		
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm
SOC	0.941**	0.902**	0.716**	0.748**	0.880**
Organic N	0.999**	0.999**	0.999**	0.999**	0.999**
Inorganic N	0.951**	0.845**	0.748**	0.793**	0.883**
			Mineralizable N		
SOC	0.883**	0.919**	0.899**	0.956**	0.946**
Organic N	0.935**	0.832**	0.714**	0.829**	0.888**
			Inorganic N		
SOC	0.920**	0.914**	0.934**	0.937**	0.926**
Organic N	0.945**	0.829**	0.734**	0.786**	0.878**
Total N	0.951**	0.845**	0.748**	0.793**	0.883**
Mineralizable N	0.988**	0.997**	0.944**	0.964**	0.954**
			NH_4^+ - N		
SOC	0.844**	0.913**	0.869**	0.902**	0.895**
Organic N	0.926**	0.839**	0.737**	0.812**	0.849**
Total N	0.931**	0.855**	0.750**	0.813**	0.852**
Mineralizable N	0.949**	0.992**	0.930**	0.924**	0.842**
			NO_3^- - N		
SOC	0.854**	0.843**	0.829**	0.761**	0.680*
Organic N	0.847**	0.734**	0.511	0.548	0.646*
Total N	0.853**	0.751**	0.524	0.557*	0.650*
Mineralizable N	0.917**	0.927**	0.699**	0.801**	0.819**

Table 5. Correlation of lower layer contents of SOC and various fractions of N with that of surface layer

N-fractions	**Correlation coefficient (r)**			
	15-30 cm	**30-45 cm**	**45-60 cm**	**60-75 cm**
SOC	0.997**	0.958**	0.933**	0.949**
Total N	0.985**	0.956**	0.975**	0.941**
Organic N	0.985**	0.952**	0.973**	0.941**
Inorganic N	0.905**	0.880**	0.906**	0.927**
Ammonium N	0.910**	0.869**	0.939**	0.930**
Nitrate N	0.844**	0.778**	0.769**	0.754**
Mineralizable N	0.842**	0.837**	0.864**	0.914**

*Like SOC, the surface layer content of N of various forms like total N (r=0.985**, 0.956**, 0.975** and 0.941**), organic N (r= 0.985**,0.952**,0.973** and 0.941**), inorganic N(r= 0.905**,0.880**,0.906** and 0.927**), ammonium N (r=0.910**, 0.869**, 0.939** and 0.930**) and Nitrate N (r=0.844**, 0.778**, 0.769** and 0.754**) were positively correlated with those of bottom layers. The results of correlation studies of SOC, organic N and inorganic N content of different layers (0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm and 60-75 cm) were found to strongly correlated with the total N content of the respective layers*

100%NPK+FYM which was at par with 100%NPK+FYM+lime. This may be attributed to better utilization of applied nutrients through the activities of greater population of soil micro-organisms which caused more nutrient transformation and also release of nutrients from organic sources that influenced more nutrient availability to the crop plants as well as the potential for higher production. Moreover, organic manures also supply growth promoting substances like enzymes and hormones [26]. Similar results were reported by Kandeshwari et al. [27]. Hence, integrated use of organic and inorganic fertilizers can make important contribution for increasing and sustaining rice production. This was also evidenced by studies of Jeyajothi and Nalliah Durai Raj [28] and Nayak et al [29].

Super optimal dose of NPK i.e., 150% NPK produced significantly higher yield (46.6 q ha^{-1}) than recommended dose i.e., 100% NPK (41.80 q ha^{-1}). The lowest grain yield (21.95 q ha^{-1}) was recorded in control. The results of twenty cycles of long-term fertilizer experiment indicated that application of 100% N alone had increased the yield by 61.7 per cent over control. The supplementation of P with N (100% NP) enhanced the yields by 15.2 per cent over 100% N treatment. Application of Zn, Zn +S and Zn + B did not have any significant effect on grain yield.

Total N uptake (Table 6) by rice crop varied from 25.2 to 97.6 kg ha^{-1}. The highest N uptake was found in 100% NPK+FYM, followed by 100% NPK+lime+FYM and the lowest N uptake (25.2 kg ha^{-1}) was observed in control plot. Similar findings were also reported by Dwivedi et al. [20] who found maximum N uptake with the treatment of integrated use of organic manure and recommended fertilizer dose as compared to control plot.

Table 6. Effect of long-term manurial practices on grain yield, N uptake and yield sustainability of rice after 10 years of continuous cropping with rice-rice system

Treatments		Kharif season Grain yield (q ha^{-1})	Total N uptake (kg ha^{-1})	Sustainable Yield Index (SYI) of the system
T-1	100% PK	32.80	48.9	0.43
T-2	100% NPK	41.80	67.0	0.45
T-3	150% NPK	46.60	92.5	0.47
T-4	100% NPK + Zn	45.05	71.9	0.45
T-5	100% NPK +FYM	51.58	97.6	0.54
T-6	100% NPK +lime +FYM	49.15	93.1	0.53
T-7	100% NPK +B +Zn	45.45	74.5	0.46
T-8	100% NPK S+ Zn	45.38	75.2	0.44
T-9	100%N	35.50	48.1	0.38
T-10	100% NP	40.90	68.3	0.41
T-11	100% NPK +Lime	43.60	75.8	0.45
T-12	Control	21.95	25.2	0.20
	$CD_{(0.05)}$	4.83	-	-

Table 7. Correlation of various pools of N of different layers with N uptake, grain yield and sustainability

	Total N				
	0-15 cm	**15-30 cm**	**30-45 cm**	**45-60 cm**	**60-75 cm**
Grain Yield	0.934**	0.923**	0.875**	0.859**	0.848**
N uptake	0.964**	0.966**	0.915**	0.925**	0.836**
Sustainability	0.902**	0.888**	0.756**	0.776**	0.786**
	Mineralizable N				
Grain Yield	0.947**	0.773**	0.750**	0.827**	0.885**
N uptake	0.958**	0.824**	0.783**	0.850**	0.892**
Sustainability	0.876**	0.765**	0.733**	0.837**	0.881**
	Inorganic N				
Grain Yield	0.924**	0.763**	0.788**	0.784**	0.780**
N uptake	0.943**	0.811**	0.819**	0.814**	0.824**
Sustainability	0.881**	0.765**	0.830**	0.847**	0.831**
	Organic N				
Grain Yield	0.931**	0.923**	0.870**	0.857**	0.848**
N uptake	0.963**	0.966**	0.911**	0.924**	0.835**
Sustainability	0.900*	0.886**	0.748**	0.771**	0.784**

***Significant at 1% level of significance; *Significant at 5% level of significance*

3.9 Correlation of Various pools of N of Different Layers with N Uptake, Grain Yield and Sustainability

The correlation coefficient values of N fractions with grain yield, N uptake and soil organic carbon content of surface soil are presented in Table 7.

Correlation of total N, inorganic N and organic N with N uptake, grain yield and sustainability revealed that these exists a strong positive correlation of all the forms of N of all the layers up to 75 cm with N uptake, grain yield and sustainability. This indicates that lower layer N forms have a strong bearing on the N uptake, grain yield and yield sustainability under low land rice-rice production system, although the treatments differ with respect to contents. This is justified by the facts that there exists a strong positive correlation of sub- soil contents various pools of N with those of top soil respectively.

4. CONCLUSION

Not only the surface soil but also the sub-soil contents of total N, organic N and mineralizable N are significantly influenced by long-term use of fertilizer nutrients and manure under wet land intensive rice production system. Sub-soil contents of total N, organic N, mineralizable N, inorganic N, ammonium N and nitrate N have strong positive correlation with those of surface layer. SOC, total N, mineralizable N and inorganic N are strongly correlated with each other in the same layer. Correlation of organic N and total N with nitrate N was however significant up to 30 cm depth and beyond that there was no correlation at 30-45 cm layer (r= 0.511 & 0.524).

From the results, it is concluded that application of nutrient in balanced and integrated manner (NPK + FYM) not only increased grain yield of rice but also improved various fractions of N in surface as well as sub-soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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