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Long-term nutrient management affects nitrogen dynamics and crop yield in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system

AJAY SHARMA[1], G S DHERI[1]* and SAT PAL SAINI[1]

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

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ABSTRACT

The present study was conducted to assess the in-season dynamics of nitrogen (N) in an Inceptisol under long-term fertilizer management in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system at Punjab Agricultural University, Ludhiana. The treatments comprised combination of chemical fertilizers (100% NPK and 150% NPK) and organic manures (100% NPK+FYM, 100% NPK+GM and 100% NPK+SI) along with unfertilized control laid out in randomized complete block design with three replications. Soil samples were collected at 30, 60, 90 and 120 days after transplanting/sowing and at harvest of rice and wheat, respectively and analysed for available N, ammonical N, nitrate N and total N. Plant samples were also collected at corresponding time period to determine the N content, uptake and biomass. Application of 100% NPK+FYM had significantly higher contents of different N forms during growth of both rice and wheat compared to rest of the treatments. At harvest of rice, combined use of 100% NPK and FYM improved soil available N and total N over 100% NPK by 20 and 22%; respectively. Whereas at wheat harvest; the increase in available and total N amounted to 29 and 23%, respectively due to corresponding treatments. The gradual decrease in N forms was observed till crop harvest. The grain and straw yield, content and total uptake of N by rice and wheat increased significantly under the integrated fertilizer management. Integrated nutrient management practice improved the relative proportion of plant-available N forms and achieved higher rice-wheat productivity.

Keywords: Long-term, Nitrogen, Rice, Wheat, Yield

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS) is the world's largest agricultural production system occupying around 10.5 m ha in India and about 85% of this area falls in Indo- Gangetic Plains (IGP) (Gopal *et al.* 2010). The importance of RWCS for food security in India is well recognizable from the significant rise in food grains production, which during the last six decades enlarged from 55 Mt in 1949-50 to 281.37 Mt during 2018-19 (Tiwari 2020). Nitrogen (N) is one of the most important mineral nutrients affecting crop productivity, emphasising maintaining adequate N supply in soil. It has been reported that significant changes in N forms occur in soil during rice-wheat cropping system reflect the dynamic nature of N. The magnitude of ammonium formation during rice growth under submerged conditions is mainly dependent on the rate of applied N and organic matter content of the soil (Patro *et al.* 2008). Integrated nutrient management (INM) is one of the most important production technology components that ensure better soil and crop productivity. The continuous addition of organic manures and inorganic fertilizers may stimulate mineralization and immobilization of plant nutrients thereby affecting their amount in different organic and inorganic forms in soil (Srivastava and Lal 1998). However, even with the escalation in input use; soils under RWCS show signs of exhaustion and no longer exhibit higher production (Benbi and Brar 2009). Depressed yields under RWCS have raised concerns about its long-term sustainability and possible adverse environmental impacts. So understanding of transformation processes of N at different crop growth periods influenced by nutrient practices will be helpful in improving the fertilizer use efficiency for achieving the goals of sustainable crop production.

Present address: [1]Punjab Agricultural University, Ludhiana.
*Corresponding author e-mail: agros.sharma08@gmail.com.

MATERIALS AND METHODS

Rice-wheat cropping system (RWCS) under long-term fertilizer experiments since 1999, in progress at Research fields, Department of Soil Science, PAU, Ludhiana was selected to conduct the present study. A field experiment [Rice (*Kharif* 2018) and Wheat (*Rabi* 2018–19)] was conducted in a fixed layout. Each treatment was replicated three times in a plot size of 108 m^2 (12 m × 9 m) in a randomized complete block design for RWCS by growing rice (cv. PR 126) and wheat (cv. Unnat PBW 550). The recommended dose of N, P and K (kg/ha) applied to rice and wheat was 120, 13, 24 and 120, 27, 24; respectively. Six fertilizer treatments of the long-term experiment were selected in the present study namely 100% NPK, 150% NPK, 100% NPK+ Farmyard Manure (FYM), 100% NPK+ Green Manure (GM), 100% NPK+ Straw Incorporation (SI) and control. The fertilizer sources of N, P and K used were urea, diammonium phosphate and muriate of potash, respectively. The full amount of P and K were applied as basal dose at the sowing time of rice and wheat. In rice planted in June, N was applied in three equal splits at 1, 3 and 6 weeks after transplanting. The November sown wheat received half of the recommended dose of fertilizer N instantly at the time of sowing and half at first irrigation. Surface (0-15 cm) soil samples from each plot were collected at 30, 60, 90 and 120 days after transplanting (DAT)/days after sowing (DAS) and at harvest of rice and wheat crop. The available N was assessed by the alkaline potassium permanganate method described by Subbiah and Asija (1956). Ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) were estimated by the method proposed by Bremner (1965). Total soil N in soil was assessed by Kjeldhal's method described by Page (1982). Shoot samples of rice and wheat were collected at 30, 60, 90 and 120 DAT/DAS and straw and grain samples at the time of crop harvest. Nitrogen was assessed in plant samples as per the procedure delineated by Jackson (1973). The N uptake was determined by multiplying yield (grain, straw) with N content. The data subjected to randomized complete block design was analyzed by analysis of variance (ANOVA) (Cochran and Cox 1967). The treatments mean effects were compared by using critical difference (CD) at $P<0.05$. Analysis was done in statistically package Duncan's Multiple Range Test (DMRT) using SPSS software.

RESULTS AND DISCUSSION

Soil nitrogen dynamics during rice-wheat season

Available N: At 30 DAT of rice, soil available N was highest in the 100% NPK+FYM (187.5 kg/ha) and lowest in control (124.2 kg/ha). At 30, 60, 90 DAT and at harvest; soil available N ranged between 124.2 to 187.5, 118.3 to 177.6, 111.3 to 162.0 and 98.8 to 142.1 kg/ha, respectively (Fig 1). The application of 100% NPK along with FYM or GM resulted in significantly higher soil available N over inorganic fertilizer application irrespective of the sampling

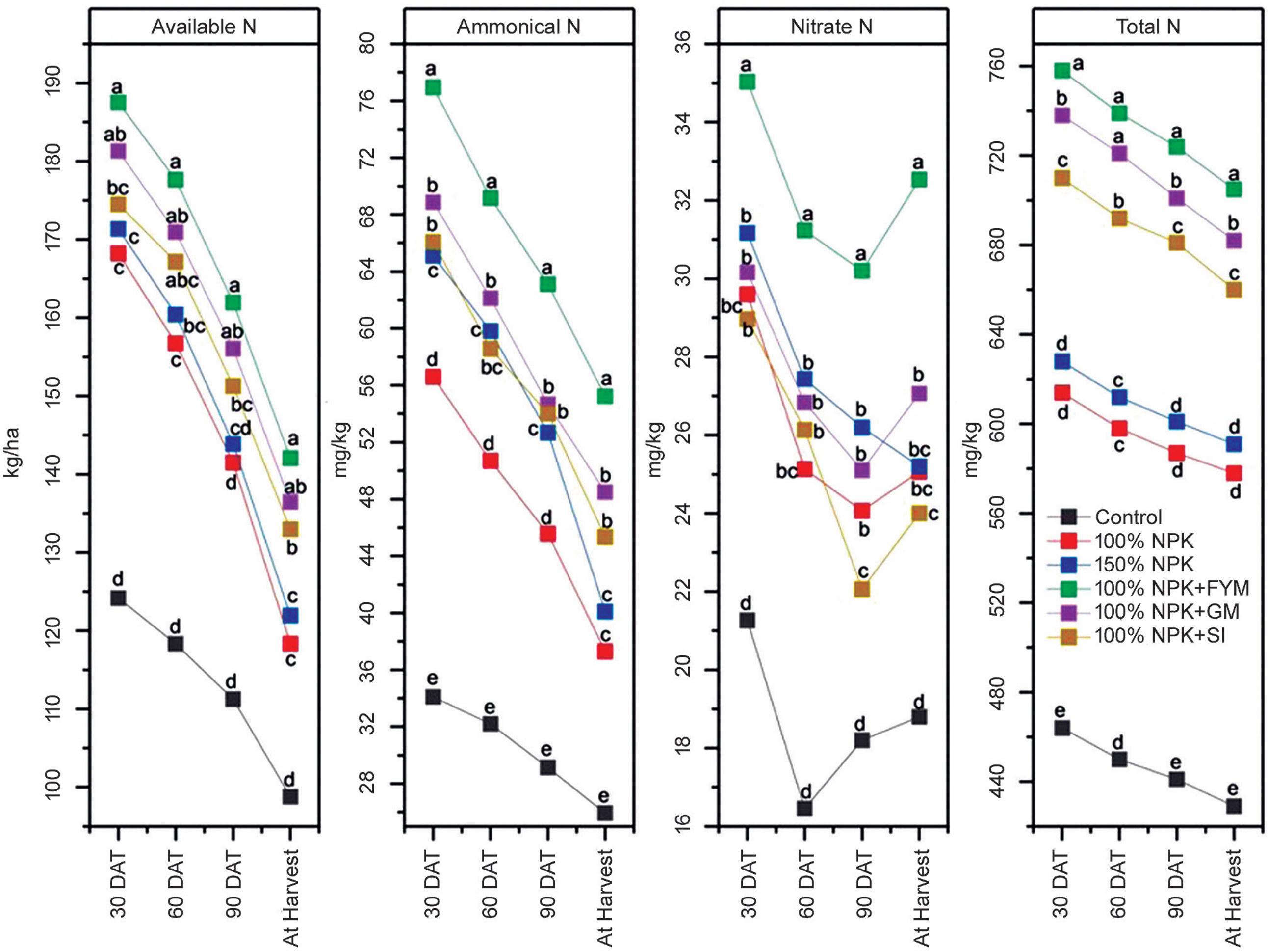

Fig 1 Effect of long-term use of inorganic and integrated fertilizers on soil N forms at different growth periods of rice. Values with different letters within the treatments at same sampling period for different N forms are significantly different at $p<0.05$ by Duncan's multiple range test (DMRT).

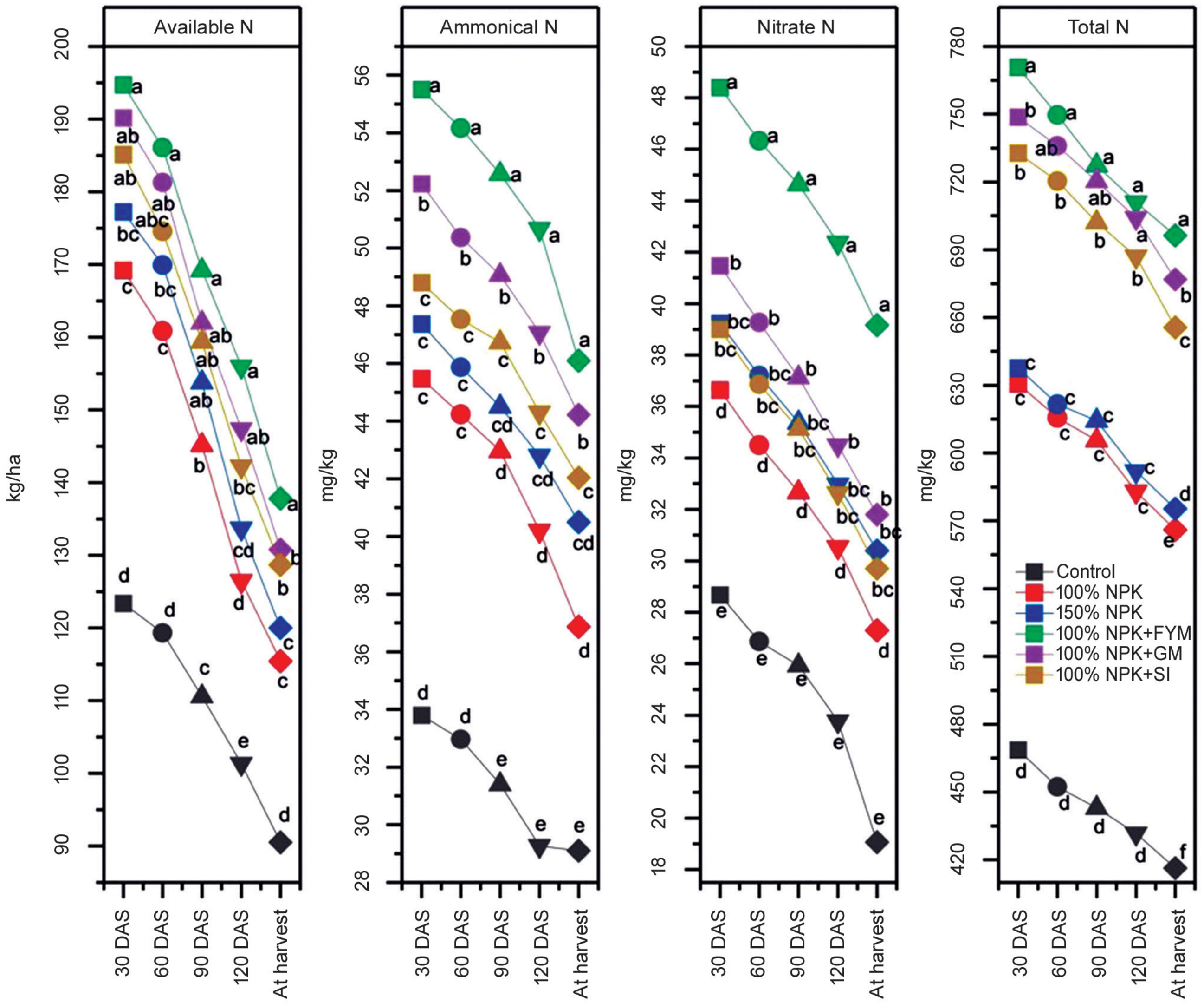

Fig 2 Effect of long-term use of inorganic and integrated fertilizers on soil N forms at different growth periods of wheat. Values with different letters within the treatments at same sampling period for different N forms are significantly different at $p<0.05$ by Duncan's multiple range test (DMRT).

period. Soil available N in different treatments declined with time and reached minimum at harvest. At harvest, improvement in available N in 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI over control was by 20, 23, 44, 38 and 35%, respectively. The enrichment in available N content in all the treatments could be attributed to continuous application of inorganic and organic fertilizers that led to the mineralization of organic N (Sharma *et al.* 2000). At 30 DAS of wheat, soil available N increased significantly from 123.4 kg/ha in control to 169.2, 177.2, 194.7, 190.2 and 185.1 kg/ha under 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI treatments, respectively (Fig 2). Soil available N in 60, 90 and 120 DAS ranged between 119.3 to 186.1, 110.6 to 169.2 and 101.3 to 155.9 kg/ha under various fertilizer treatments. At harvest; available N ranged between 90.5 kg/ha in control to 137.8 kg/ha in FYM integrated plots. Significant and maximum improvement in available N was recorded under the integrated nutrient management practices (100% NPK+FYM and 100% NPK+GM) and it was more than control by 52 and 45%, respectively. The significantly higher available N under integrated treatment of 100% NPK+FYM might be attributed to an increase in biological activity and soil organic carbon content of soil.

Ammonical nitrogen (NH_4^+*-N)*: NH_4^+-N content at 30 DAT of rice crop ranged from 34.1 mg/kg in control to 76.9 mg/kg in FYM amended treatment. NH_4^+-N content increased to 56.6, 65.1, 76.9, 68.9 and 66.1 mg/kg with the application of 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI, respectively from its control value of 34.1 mg/kg (Fig 1). NH_4^+-N content in soil samples at 60, 90 DAT and at harvest; ranged between 32.2 to 69.2, 29.1 to 63.1 and 25.9 to 55.2 mg/kg, respectively, under different fertilizer treatments. Across the growth periods of rice, NH_4^+-N content increased substantially with the integrated use of inorganic fertilizers and FYM compared to 100% NPK. Data (Fig 2) revealed that the NH_4^+-N content at 30 DAS of wheat increased from 33.8 mg/kg in control to 45.5, 47.4, 55.5, 52.2 and 48.8 mg/kg with the application of 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI, respectively. NH_4^+-N content ranged between 33.0 to 54.2, 31.4 to 52.6, 29.3 to 50.7 and 29.1 to 46.1 mg/kg at 60, 90, 120 DAS and at harvest of wheat crop. In control, NH_4^+-N was recorded low in comparison to the integrated use of manures and inorganic fertilizers; which indicated that only a small portion of the organic N is mineralized at a given point of time (Jadhao *et al.* 2019).

Nitrate nitrogen (NO_3^--N): NO_3^--N content in soil samples at 30, 60, 90 DAT and at harvest of rice; ranged between 21.3 to 35.0, 16.5 to 31.2, 18.2 to 30.2 and 18.8 to 32.5 mg/kg, respectively under different fertilizer treatments (Fig 1). Build-up of NO_3^--N in soils was with the integrated use of 100% NPK+FYM. At harvest, improvement of NO_3^--N in 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI over control was by 33, 34, 73, 44 and 28%, respectively. The increase in NO_3^--N content might be attributed to the addition of higher amount of biomass which enhanced the microbial activity (Singh 2010). The NO_3^--N values ranged between 28.7 and 48.4 mg/kg at 30 DAS of wheat crop. NO_3^--N was recorded minimum in control and maximum in 100% NPK+FYM. NO_3^--N increased from 28.7 in control to 36.6, 39.2, 48.4, 41.5 and 39.0 mg/kg with the application of 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI, respectively (Fig 2). Significant improvement of NO_3^--N among alone application of inorganic fertilizers, i.e. 100% NPK, 150% NPK over control was by 43 and 59%, respectively. Loss of NO_3^--N in soil could be reduced or avoided by applying N fertilizer in an amount less than or equal to that necessary for the optimal crop yield (Xu *et al.* 2020).

Total N: At 30 DAT, total N content in rice crop varied from 464 mg/kg in control to 758 mg/kg in 100% NPK+FYM. At 60, 90 DAT and crop harvest; it ranged between 450 to 739, 441 to 724 and 429 to 705 mg/kg, respectively (Fig 1). Total N content decreased with the advancement of crop growth. The higher total N in soils under integrated nutrient management practices over sole application of inorganic fertilizers (100% NPK and 150% NPK) might be accredited to higher accumulation of organic N and immobilization of mineral-N by FYM. Data from Fig 2 revealed that in wheat at 30 DAS; total N varied from 469 in control to 771 mg/kg in 100% NPK+FYM. It

Table 1 Effect of long-term use of inorganic and integrated fertilizers on N content, uptake and dry matter accumulation at different growth periods of rice

Treatment	30 DAT	60 DAT	90 DAT	At harvest	
				Grain	Straw
			N content (%)		
Control	2.56^{c}	1.73^{c}	1.17^{c}	1.03^{c}	0.34^{e}
100% NPK	3.39^{b}	2.69^{b}	1.49^{b}	1.26^{b}	0.56^{d}
150% NPK	3.53^{b}	2.77^{b}	1.55^{b}	1.24^{b}	0.58^{cd}
100% NPK+FYM	3.78^{a}	3.04^{a}	1.75^{a}	1.37^{a}	0.66^{a}
100% NPK+GM	3.74^{a}	2.99^{a}	1.69^{a}	1.33^{a}	0.65^{ab}
100% NPK+SI	3.68^{a}	2.75^{b}	1.53^{b}	1.26^{b}	0.61^{bc}
			Total N uptake (kg/ha)		
Control	6.53^{e}	30.4^{d}	33.5^{d}	30.4^{c}	11.0^{d}
100% NPK	18.3^{cd}	82.2^{c}	90.0^{c}	75.9^{b}	36.6^{c}
150% NPK	18.0^{d}	81.9^{c}	90.7^{c}	73.8^{b}	37.3^{c}
100% NPK+FYM	22.9^{a}	109.0^{a}	121.3^{a}	95.0^{a}	49.5^{a}
100% NPK+GM	19.2^{bc}	87.0^{bc}	98.3^{b}	78.1^{b}	40.9^{b}
100% NPK+SI	20.1^{b}	91.5^{b}	101.8^{b}	82.3^{b}	43.1^{b}
			Dry matter accumulation (Mg/ha)		
Control	0.26^{d}	1.75^{d}	2.85^{e}	2.95^{c}	3.21^{d}
100% NPK	0.54^{b}	3.05^{c}	6.02^{c}	6.03^{b}	6.50^{bc}
150% NPK	0.51^{c}	2.96^{c}	5.85^{d}	5.95^{b}	6.42^{c}
100% NPK+FYM	0.61^{a}	3.59^{a}	6.93^{a}	6.94^{a}	7.52^{a}
100% NPK+GM	0.52^{c}	2.91^{c}	5.83^{d}	5.87^{b}	6.28^{c}
100% NPK+SI	0.55^{b}	3.32^{b}	6.67^{b}	6.51^{ab}	7.04^{ab}

Values with different letters are significantly different at $P<0.05$ by Duncan's multiple range test (DMRT) increased from 469 in control to 631, 638, 771, 749 and 733 mg/kg with the application of 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI, respectively. Total N content ranged between 452 to 750, 443 to 727, 432 to 711 and 416 to 696 mg/kg in 60, 90, 120 DAS and wheat harvest. At harvest, in FYM amended plots total N was reported significantly higher over control, 100% NPK and 150% NPK by 67, 23 and 21%, respectively. The maximum value of total N under integrated application of FYM with inorganic fertilizers could be attributed to the addition of organic matter, root biomass and root exudates (Durani *et al.* 2016).

Nitrogen content, uptake and yield in rice-wheat

N Content in rice-wheat: At 30, 60 and 90 DAT of rice, N content varied from 2.56 to 3.78, 1.73 to 3.04 and 1.17 to 1.75% under different fertilizer applications, respectively (Table 1). The increase in N content in grain with the application of 100% NPK, 150% NPK, 100% NPK+FYM, 100% NPK+GM and 100% NPK+SI over control was 22, 20, 33, 29 and 22%, respectively. A significant increase in the grain N content was recorded under the FYM amended treatment which was higher by 8 and 10% over the application of 100% NPK and 150% NPK, respectively. Straw N content varied from 0.34% under control to 0.66% under 100% NPK+FYM. Straw N content under integrated application of FYM or GM with 100% NPK was at par. Low N concentrations in plant leaves were responsible for reduced biomass productivity, resulting in lower dry matter production of rice (Kiniry *et al.* 2001). At 30 DAS of wheat, N content varied from 4.12 to 5.12% (Table 2). About 50% reduction was observed at 60 DAS over 30 DAS. At 90 DAS and 120 DAS, FYM amended plots had significant higher N content over all other treatments. The grain N content varied from 1.05 in control to 1.72% in 100% NPK+FYM, respectively. Higher N content was observed in the initial stages. This indicates that the capacity of accumulation N in wheat during growth is highest at the initial stages. After that as the biomass of plant increase, the concentration of N in plants gets diluted (Mandal *et al.* 2009).

Total N uptake: At 30 DAT, N uptake in rice crop varied from 6.53 in control to 22.9 kg/ha in FYM amended plots (Table 1). At 30, 60 and 90 DAT, N uptake in different treatments ranged between 6.53 to 22.9, 30.4 to 109.0 and 33.5 to 121.3 kg/ha, respectively. The increase in grain N uptake in FYM amended treatment was higher by 25 and 29% significant over sole application of inorganic fertilizers (100% NPK and 150% NPK), respectively. The total N uptake under GM and SI amended treatments was at par at all growth periods of rice crop. At 30 DAS, total

Table 2 Effect of long-term use of inorganic and integrated fertilizers on N content, uptake and dry matter accumulation at different growth periods of wheat

Treatment	30 DAS	60 DAS	90 DAS	120 DAS	At harvest	
					Grain	Straw
			N content (%)			
Control	4.12^{d}	2.28^{d}	0.90^{c}	0.85^{c}	1.05^{d}	0.26^{c}
100% NPK	4.91^{bc}	2.51^{c}	1.38^{b}	1.34^{b}	1.52^{c}	0.47^{b}
150% NPK	4.90^{bc}	2.59^{c}	1.43^{b}	1.39^{b}	1.55^{bc}	0.47^{b}
100% NPK+FYM	5.12^{a}	2.89^{a}	1.61^{a}	1.57^{a}	1.72^{a}	0.56^{a}
100% NPK+GM	4.74^{c}	2.59^{c}	1.39^{b}	1.34^{b}	$1.65a^{b}$	0.53^{ab}
100% NPK+SI	4.95^{ab}	2.76^{b}	1.50^{ab}	1.42^{b}	1.55^{bc}	0.54^{a}
			Total N uptake (kg/ha)			
Control	4.71^{c}	5.02^{e}	11.8^{e}	12.3^{e}	13.9^{d}	4.10^{d}
100% NPK	9.21^{b}	16.3^{d}	64.3^{d}	65.1^{d}	66.2^{c}	24.0^{c}
150% NPK	9.90^{b}	18.1^{c}	70.8^{c}	72.3^{c}	69.9^{c}	25.7^{c}
100% NPK+FYM	12.8^{a}	23.4^{a}	92.8^{a}	96.5^{a}	86.4^{a}	36.0^{a}
100% NPK+GM	10.1^{b}	18.4^{c}	71.6^{c}	72.8^{c}	78.0^{b}	29.9^{b}
100% NPK+SI	10.7^{b}	20.2^{b}	84.8^{b}	86.1^{b}	77.4^{b}	34.4^{a}
			Dry matter accumulation (Mg/ha)			
Control	0.11^{c}	0.22^{d}	1.31^{d}	1.45^{e}	1.33^{c}	1.55^{d}
100% NPK	0.19^{b}	0.65^{c}	4.65^{c}	4.85^{d}	4.36^{b}	5.10^{c}
150% NPK	0.20^{b}	0.70^{bc}	4.96^{b}	5.21^{c}	4.44^{b}	5.47^{b}
100% NPK+FYM	0.25^{a}	0.81^{a}	5.77^{a}	6.15^{a}	5.00^{a}	6.36^{a}
100% NPK+GM	0.21^{b}	0.71^{b}	5.14^{b}	5.45^{b}	4.73^{ab}	5.65^{b}
100% NPK+SI	0.22^{ab}	0.73^{b}	5.65^{a}	6.05^{a}	5.00^{a}	6.30^{a}

Values with different letters are significantly different at P<0.05 by Duncan's multiple range test (DMRT).

N uptake by wheat varied from a minimum of 4.71 kg/ha in control to a maximum of 12.8 kg/ha in FYM amended treatment (Table 2). A significant increase in N uptake could be due to an increase in the nutrient concentration of grain and straw and an increase in total dry matter production. Prasad *et al.* (2010) also observed that maximum N uptake was recorded in the integrated application of organic and inorganic fertilizers.

Periodic dry matter accumulation: With the advancement in the age of rice crop from 30 to 90 DAT, there was a gradual increase in dry matter production irrespective of fertility levels (Table 1). The magnitude of increase was highly pronounced from 30 DAT to 60 DAT. Grain yield of rice ranged from 2.95 Mg/ha in control to 6.94 Mg/ha in 100% NPK+FYM. Grain yield in SI treated plots was statistically at par with GM amend plots. Straw yield varied from 3.21 Mg/ha to 7.52 Mg/ha in control and 100%NPK+FYM, respectively. Higher grain yield and dry matter accumulation in organics amended plots could be attributed to better synchrony of nutrient availability under integrated use of organic and inorganic fertilizer sources (Ahmed *et al.* 2014). At all growth periods of wheat crop, 100% NPK+FYM had resulted in significantly higher dry matter than other treatments except 100% NPK+SI (Table 2). Grain yield of wheat varied between 1.33 Mg/ha in control to 5.00 Mg/ha in 100% NPK+FYM treatment. Grain yield in FYM and SI treated plots was statistically at par with GM amended plots. Straw yield varied from 1.55 Mg/ha to 6.36 Mg/ha in control and 100% NPK+FYM, respectively. Higher dry matter accumulation in integrated fertilization over sole inorganic treatments signifies the importance of the balanced use of inorganic fertilizers and organic manures (Nishant *et al.* 2016).

The present study conclude that long-term application of organic manures in conjunction with inorganic fertilizers strongly influenced N transformations in rice and wheat at different growth periods of crop. FYM integrated inorganic fertilizer treatment had resulted significantly higher values of different N forms during growth of rice and wheat over the rest of the treatments. The periodic dry matter production, grain and straw yield, content and total uptake of N by rice and wheat was increased significantly under integrated nutrient management. The overall result suggests that integrated nutrient management enhanced the contents of available N forms at different growth periods of crops to achieve maximum yield and better nutrient uptake in rice-wheat cropping system.

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