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Nitrogen management in transplanted rice (*Oryza sativa*) in mid hill acidic soils of Sikkim Himalayas

RAVIKANT AVASTHE

ICAR Research Complex for NEH Region, Sikkim Centre, Tadong, Gangtok, Sikkim 737 102

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ABSTRACT

Two field experiments were conducted at Tadong in Sikkim in the humid mid-hill acidic soils during rainy (*kharif*) season of 2004, 2005 and 2006 to optimize the rate, source and schedule of nitrogen management for increasing the yield and nitrogen-use efficiency of transplanted rice (*Oryza sativa* L.) under 9 schedules, 4 rates (0, 80, 120 and 160), 3 nitrogen sources (urea, farm yard manure and neem cake-coated urea) in comparison with farmers' practices. N application @ 80 kg/ha as ¼ N 10 days after transplanting (DAT) + ¼ N at maximum tillering (MT) + ½ at panicale initiation (PI) recorded the highest yield (5.44 t/ha), recovery efficiency (82%) and agronomic efficiency (47.9 kg grain / kg N applied). The grain yield increased with increase in the N rate from 80 to 160 kg/ha. Conjunctive application of FYM and urea increased the N uptake by 11.1 to 26.2%, recovery efficiency (11.1 to 46.7%) and agronomic efficiency (5.4 to 14.8 %). Basal application of FYM @ 2.5 t/ha and top-dressing 80 kg N/ha through urea as ¼ N at 10 DAT + ¼ N at MT+ ½ at PI stage recorded the highest recovery efficiency (66.3%) and agronomic efficiency (38.7 kg grain / kg N applied). At 120 kg N/ha neem cake increased the recovery efficiency by 12.1 and 37.6% and agronomic efficiency by 9.9 and 15.8% over N_{120} with and without FYM. Farmers' practice of application of FYM basal @ 5 t/ha and FYM @ 2.5 t/ha along with top-dressing of DAP @ 40 kg/ha at PI gave low yield and N-use efficiency.

Key words: Acidic soils, Farmyard manure, Mid hill, Rates, Schedule, Sikkim Himalayas, N sources, Urea

Rice (*Oryza sativa* L.) is the second most important cereal of Sikkim, cultivated on 14,150 ha with an average yield 1,516 kg/ha (Anonymous, 2007). The production levels are below the regional and national averages, providing ample scope for increasing both production and productivity. The low-yields of rice in Sikkim can be related to palatability preference for low yielding traditional cultivars, partial implementation of recommended management practices, low nutrient input etc. Since 1975 the State Agriculture Department has introduced many high-yielding varieties (HYVs) of rice, yet the traditional cultivars occupy almost 50% of the net sown area. These HYVs are also cultivated under low input management. Nutrient management at farmers' fields is limited to farmyard manure (FYM) @ 2.5 to 5 t/ha as basal dose with or without top-dressing of diammonium phosphate (DAP) @ 20 to 40 kg/ha at panicle-initiation stage. Low use efficiency of applied nitrogen under submerged conditions has been well documented for plains under various management practices (Barla and Upasani, 2008; Singh *et al*., 2001), but no studies are available on the response of transplanted HYV of rice to nitrogen management under submerged acidic soils of mid-hill conditions of Sikkim. Hence this study was conducted using different nitrogen sources and rates in comparison with farmers' practices to optimize the rate, source and schedule of nitrogen management for increasing the yield and N-use efficiency of transplanted rice.

Corresponding author: E-mail: ravisikkim@yahoo.co.in

MATERIALS AND METHODS

Two field experiments were simultaneously conducted on rice at the ICAR Sikkim Research Farm, Tadong, located at an altitude of 1,400 m above mean sea-level in the humid mid-hill acidic soils during rainy (*kharif*) seasons of 2004, 2005 and 2006. The first experiment was laid out in randomized block design with 10 treatments and 4 replications. These nitrogen treatments were: T_1, no nitrogen (the control); T_2, full N through FYM broadcast and incorporated (BI); T_3, ½ N through FYM (BI) + ½ N top-dressed at maximum tillering stage; T_4, ½ N at 10 days after transplanting (DAT) + ½ N at maximum tillering (MT) stage; T_5, full N top-dressed at 10 DAT; T_6, ⅓ N BI at transplanting + ⅓ N at maximum tillering + ⅓ N at panicle initiation (PI); T_7, ¼ N at 10 DAT + ¼ N at maximum tillering + ½ at PI; T_8, ½ N BI at transplanting + ¼ N at maximum tillering + ¼ at PI; T_9, ½ N BI at transplanting + ½ N at 7 days before panicle initiation (DBPI); T_{10}, ¼ N BI at transplanting + ¼ N at 10 DAT + ¼ N at maximum tillering + ¼ N at PI.

The second experiment, conducted simultaneously, was also laid out in randomized block design with 9 treatments and 4 replications. In this experiment different sources and doses of nitrogen were applied as: nitrogen sole application through urea @ 80, 120 and 160 kg N/ha as ¼ N at 10 DAT + ¼ N at maximum tillering + ½ at PI alone (T_1-T_4); and in conjunction with broadcast and incorporation of well-rotten FYM @ 2.5 t/ha (T_5-T_8), along with farmer's practices. Slow-release N fertilizer as neem-coated urea, produced by coating urea with neem-seed cake @ 20% the weight of urea with coal tar solution in kerosene as binding solution, was applied @ 120 kg N/ha basal just before transplanting. The nutrient management of farmers of Sikkim for rice production consisted of two practices; viz. F_1, FYM was applied basal @ 5 t/ha to supply 20 kg N/ha; and F_2, FYM @ 2.5 t/ha and DAP top-dressed @ 40 kg/ha at panicle initiation to provide 40 kg N/ha. FYM contained 0.40% N, 0.92% P, 0.43% K, and 0.31% organic carbon, with 17.3:1 C:N ratio.

In both the experiments 25 day-old seedlings of 'Pant Dhan 10' were transplanted at 20 x 15 cm spacing with 2 seedlings/hill. The flood-water level of 10 cm was maintained in all the plots till the flowering stage. The clay loam soils had pH 5.35, organic carbon 1.85%, available N (alkaline $KMnO_4$) 212.3 kg/ha, available (Brays' P_1) P 26.4 kg/ha, available K (NH_4OAc-extractable) 197.1 kg/ha, and (CEC) 15.6 cmol(p^+)/kg. N, P and K were applied @ of 80, 60 and 40 kg/ha, through FYM (in terms of organic equivalents), urea, single superphosphate and muriate of potash respectively, with full P and K as basal dose. FYM was applied basal 3 days before transplanting in both the experiments.

RESULTS AND DISCUSSION

Effect on growth

Different schedules of N application showed significant effect on effective tiller density and panicle length at harvest for all the treatments including the farmers' practice (Table 1), recording higher values for split application. Maximum tiller density and panicle length observed in the treatment ¼ N 10 DAT + ¼ N at MT + ½ at PI (T_7) showed the benefit of split application ensuring continued N availability compared with single application. Ladha *et al*. (1998) reported similar findings. The panicles in the farmers' practice were significantly shorter than all the other treatments.

The rates and sources of N significantly influenced the effective tiller density and panicle length, which increased with increase in N rate (Table 2). Integration of N_{160}+$FYM_{2.5t/ha}$ produced the highest tiller density and panicle length, which resulted in the highest rice yield. N_{120} + $FYM_{2.5\ t/ha}$ recorded higher tiller density and panicle length than NCU_{120}, indicating its ability for sustained N supply.

Effect on yield

Different schedules of nitrogen application (Experiment 1) produced significantly higher rice-grain yield than the control, which increased progressively during the 3 years of study (Table 1). Three split N applications as ¼ N at 10 DAT + ¼ N at MT + ½ at PI (T_7) recorded the highest yield in all the 3 years, with an increasing trend from 4.9 to 5.6 t/ha, being 6.3 to 45.2% higher than under other schedules. Delay in the basal dose till 10 DAT ensured establishment of seedlings, and split application at crucial stages of maximum tillering and panicle initiation resulted in higher absorption and translocation of nitrogen to effective plant parts, i.e. flag leaf and panicles, and reduced the losses, resulting possibly in high grain yields (Ladha *et al*., 1998). Application of N_{80} wholly through FYM produced the lowest grain yield, perhaps because of its inability to synchronize the N supply with all the growth stages. Top-dressing of full N dose at 10 DAT also proved ineffective. Application of half the N dose basally either as urea or FYM did not result in significant gain in yield compared with that where it was applied at 10 DAT. Three and four split applications of nitrogen were significantly different from each other and superior to other treatments, which could be due to better supply of N at crucial growth stages, confirming the finding of Singh *et al*. (2007). Higher leaching and overflow losses resulted in significantly lower yield with 4 splits than with 3 split applications. The farmers' application of FYM @ 5 t/ha proved inadequate in terms of N supply required for high yield and produced only 1.93 to 2.13 t/ha, which was significantly higher only over the control. The increase in straw yield each year under the influence of various N schedules was significantly higher over than the control. Straw production showed similar trend as grain yield.

All the treatments and the farmers' practice generated higher harvest index (HI) values than the control. Benefits of delayed application of half the N dose until the PI stage were reflected in the highest HI for 3 consecutive years that ranging from 46.8 to 48.9, whereas the farmers' practice produced the lowest HI.

All the rates and sources of N application (Experiment 2) produced yields significantly different from each other and higher than the N_0 control. Rice yield increased with increase in N level from 80 to 160 kg/ha in both sole application as well as in conjunction with FYM, but it decreased in the third year at higher rates due to the incidence of leaf and neck blast. Application of 80 kg N/ha increased the yield by 120 to 156% over the control; the increases were larger at higher rates of N application (Table 2). Amalgamation of N_{160}+$FYM_{2.5}$ t/ha produced the highest grain yield, whereas the farmers' practice also yielded 63 to 70% more than the control. Nitrification inhibition induced by NCU_{120} increased the yield by 210 to 234% over the control and 6.0 to 16.0% over N_{120} and N_{120}+$FYM_{2.5t/ha}$. Higher N application increased the N uptake, leading to greater dry-matter production and its translocation towards sink (Dar *et al*., 2000). The farmers' practice that supplied only 40 kg N/ha yielded more than the control but significantly lower than all the other treatments. An increase in the N rate from 80 to 120 kg/ha and doubling to 160 kg/ha increased the yield by 23.8% and 37.8% respectively, but when it was increased from 120 to 160 kg/ha the increase was only 11.2%. Application of N_{160}+$FYM_{2.5\ t/ha}$ produced the highest straw yield. The straw yield showed similar trend as grain yield and increased with increase in N rate. All the treatments including the farmers' practice recorded higher HI values than the control, the highest HI was recorded for the combined application of N_{160}+ $FYM_{2.5\ t/ha}$ in all the 3 years. HI was higher when urea was combined with FYM and increased with the increase in N rate.

Effect on N uptake

Split application of ¼ N 10 at DAT + ¼ N at MT + ½ at PI (T_7) resulted in the maximum uptake of N which was significantly higher (7.9 to 112.5%) than other schedules (Table 3). The total N uptake at harvest was significantly influenced by N fertilization, showing significant variation between schedules and over the control. The short supply of N in the farmers' practice was amply reflected by the lowest N uptake. This perhaps could be related to slow decomposition rate of FYM in submerged conditions under the maximum air temperature of 25 to 29°C during the rainy (*kharif*) season. These findings are in consonance with those of Ladha *et al*. (1998).

The rates and sources of N showed significant differences in N uptake amongst the treatments (Table 3). Integration of FYM with urea resulted in significantly higher uptake at all the rates of nitrogen application. N_{160}+$FYM_{2.5\ t/ha}$ recorded the highest uptake that increased with the rate of N application. An increase in N level from 80 to 120 kg/ha and to 160 kg/ha increased the uptake by 30.7 and 55.6%, respectively, but that from 120 to 160 kg/ha increased the uptake by 19% only. Similarly, the N uptake increased by 11.1 to 26.2% on integration with FYM. Nitrification inhibition through neem cake increased the up-

Table 1. Effect of schedule of nitrogen application on yield and growth of transplanted rice

Treatment	Yield (t/ha)						Harvest Index			Effective tillers/m²			Panicle length (cm)		
	2004		2005		2006		2004	2005	2006	2004	2005	2006	2004	2005	2006
	Grain	Straw	Grain	Straw	Grain	Straw									
T_1, No-nitrogen control	1.52	3.27	1.64	3.54	1.66	3.73	31.7	31.7	30.8	148	154	158	23.3	23.5	23.7
T_2, Full N through FYM B & I	2.79	4.35	2.92	4.41	3.22	4.77	39.1	39.8	40.3	212	220	230	23.6	23.9	24.0
T_3, ½ N through FYM (BI) + ½ N top-dressed at MT	3.28	4.84	3.48	5.03	3.68	5.20	40.4	40.9	44.4	239	248	256	23.8	24.1	24.4
T_4, ½ N 10 DAT + ½ N at MT	3.94	5.25	4.16	5.47	4.35	5.48	42.8	43.2	44.3	260	272	280	24.1	24.4	24.7
T_5, Full N top-dressed 10 DAT	3.35	5.14	3.56	5.35	3.83	4.90	39.5	39.9	43.8	228	240	261	23.7	24.2	24.5
T_6, ⅓ N BI at transplanting + ⅓ N at MT + ⅓ N at PI	4.64	6.00	4.89	6.20	5.14	6.08	43.6	44.1	45.8	284	295	311	24.5	25.1	25.5
T_7, ¼ N 10 DAT + ¼ N at MT + ½ at PI	5.25	5.97	5.47	5.78	5.60	5.84	46.8	48.6	48.9	312	325	334	25.6	26.3	26.8
T_8, ½ N BI at transplanting + ¼ N at MT + ¼ at PI	4.90	6.65	5.17	6.23	5.28	6.00	42.4	45.4	46.8	290	302	318	24.7	25.5	25.8
T_9, ½ N BI at transplanting + ½ N at 7 DBPI	3.15	4.04	3.38	4.16	3.56	4.30	43.8	44.8	45.3	240	253	259	23.9	24.4	24.7
T_{10}, ¼ N BI at transplanting + ¼ N 10 DAT + ¼ N at MT + ¼ N at PI	4.26	5.03	4.48	5.12	4.65	5.15	45.9	46.7	47.5	272	284	294	24.1	24.8	25.0
Farmers' practice	1.93	3.58	2.01	3.71	2.13	3.85	35.0	35.1	35.6	184	190	202	23.5	23.7	23.8
SEm±	0.13	0.17	0.12	0.18	0.11	0.20				8.0	9.5	7.3	0.13	0.17	0.2
CD (P=0.05)	0.37	0.51	0.35	0.54	0.32	0.58				24	28	22	0.4	0.5	0.6

*Farmers' practice: FYM @ 5 t/ha = 20 kg N/ha take by 8.5 and 24.8% over N_{120} and N_{120}+$FYM_{2.5t/ha}$, respectively. Higher concentration of N in rhizosphere led to higher N uptake by the plant biomass. Rice plant prefers NH_4^+-N at early stage of the crop growth, which was higher under continuous submergence, probably due to the slow rate of nitrification prevailing under oxygen-stress condition (Manguiat *et al*., 1994). The integration of chemical fertilizer with organic fertilizer such as FYM improved the productivity because of nutritional and growth-stimulating substances (Sharma and Mittra, 1988).

Effect on N-use efficiency

Nitrogen-use efficiency in terms of recovery efficiency and agronomic efficiency was higher for 3 and 4 split applications of N compared with other schedules, pointing to lower losses and higher N availability for longer duration. A reverse trend was observed for production efficiency (PE). Maximum recovery efficiency and agronomic efficiency were observed for ¼ N at 10 DAT + ¼ N at MT + ½ at PI, which was 11.1 to 97.1% and 9.0 to 180.1% higher under than other schedules (Table 3). It strengthens the argument that higher NUE with one-fourth split application of fertilizer dose at 10 DAT may be due to better translocation, distribution and remobilization of absorbed N in different plant organs, i.e. flag leaf and spikelets, with which N is used in CO_2 fixation (Ladha *et al*., 1998). The farmers' practice proved to be an inefficient schedule of N management.

Agronomic efficiency and production efficiency decreased with increase in N level from 80 to 160 kg/ha and was higher when integrated with FYM (Table 3). The highest values of AE and PE were observed for N_{80} + $FYM_{2.5\ t/ha}$ and farmers' practice. When N level was increased from 80 to 120 kg/ha and to 160 kg/ha the agronomic efficiency decreased by 6.6 and 21.7% respectively, whereas when it was raised from 120 to 160 kg/ha AE decreased by 14.1%. Conjunctive application of urea + FYM increased the AE by 5.4 to 14.8%. This amalgamation also provided greater stability in crop production and increased the nutrient-use efficiency due to modification of the soil physical behaviour (Nambiar and Abrol, 1992). Recovery efficiency decreased with increase in N rate in the integrated mode, but the trend was erratic for urea alone. At N_{120} neem cake increased the RE by 12.1 and 37.6% and AE by 9.9 and 15.8% compared with N_{120} with or without FYM. It confirms the finding of Mishra (1992), and could be attributed to lower leaching losses of nitrate-N caused by the inhibitory effect of neem cake.

Economics

The highest net return and benefit : cost (B:C) ratio were recorded for 3-split N applications as ¼ N at 10 DAT + ¼ N at MT + ½ at PI amongst the various N application schedules evaluated (Table 3). Split applications generally realized higher net return. The net return and benefit : cost, however, increased with the increase in N level from 80 to 160 kg N/ha. Maximum return and net return/Re invested were highest with N_{160}. Conjunctive application of FYM with highest return was also observed at $N_{160,}$ but the highest net return/Re invested was recorded at $FYM_{2.5t}$+N_{80}, perhaps because of the lower cost of cultivation. Neem-coated urea was also cost effective, with a return of Rs 69,850 and benefit : ratio, ratio 1.81. The farmers' practices brought the lowest return in this study.

Three-split N applications as ¼ N at 10 DAT + ¼ N at MT + ½ at PI showed the best performance amongst the various N application schedules evaluated. However, the study reveals that the schedule of broadcast and incorporation of FYM @ 2.5 t/ha 3 days before transplanting, followed by top-dressing of 80 kg N/ha through urea as ¼ N

Table 2. Effect of nitrogen application on yield and growth of transplanted rice

Treatment	Yield (t/ha)						Harvest-index			Effective tillers/m²			Panicle length (cm)		
	2004		2005		2006		2004	2005	2006	2004	2005	2006	2004	2005	2006
	Grain	Straw	Grain	Straw	Grain	Straw									
T_1, No-N control	2.03	4.14	1.96	3.88	1.87	3.76	32.9	33.6	33.2	151	157	148	23.8	23.4	23.2
T_2, N_{80}	4.49	5.51	4.66	5.42	4.78	5.58	44.9	46.2	46.1	224	242	263	24.7	24.3	24.6
T_3, N_{120}	5.64	6.12	5.89	6.16	5.71	6.14	48.0	48.9	48.2	276	288	279	25.5	24.5	24.7
T_4, N_{160}	6.37	6.89	6.54	6.67	6.27	6.45	48.0	49.5	49.3	324	335	327	25.8	24.8	24.9
T_5, $FYM_{2.5t}$+N_{80}	4.85	5.27	5.07	5.39	5.22	5.65	47.9	48.5	48.0	297	308	295	25.2	24.6	24.4
T_6, $FYM_{2.5t}$+N_{120}	5.82	6.11	6.14	6.35	5.89	6.07	48.8	49.2	49.3	339	357	347	25.8	24.9	24.7
T_7, $FYM_{2.5t}$+N_{160}	6.54	6.65	6.72	6.64	6.63	6.54	49.9	50.3	50.3	374	386	379	26.1	25.2	25.1
T_8, NCU-N_{120}	6.30	6.42	6.48	6.71	6.25	6.14	49.5	49.1	50.4	289	311	302	25.1	24.7	24.5
T_9, FP	3.31	5.08	3.24	5.20	3.18	5.36	39.5	38.4	37.2	178	172	166	23.9	23.7	23.4
SEm±	0.16	0.18	0.17	0.23	0.16	0.17				2.9	5.0	4.1	0.2	0.17	0.16
CD (P=0.05)	0.46	0.54	0.51	0.66	0.47	0.51				11	15	13	0.6	0.5	0.5

FP: Farmers' practice: FYM @ 5t/ha + DAP @ 40 kg/ha= 40 kg N/ha

Table 3. Effect of nitrogen management on N uptake, N-use efficiency and economics of transplanted rice (pooled data of 3 years)

Treatment	Total N uptake at harvest (kg/ha)	N use efficiency			Net return (x 10^3 Rs/ha)	Benefit : Cost ratio
		RE (%)	AE	PE		
Experiment 1						
T_1, Control	22.8				18.58	1.08
T_2, 20 t FYM	41.6	23.5	17.1	72.8	22.79	1.24
T_3, 10 t FYM + N_{40}	51.1	35.3	23.4	66.3	39.82	1.71
T_4, N_{40} + N_{40}	61.3	48.0	31.8	66.1	46.90	1.71
T_5, N_{80}10 DAT	54.2	34.5	24.7	71.3	40.93	1.53
T_6, N_{27} + N_{27} + N_{27}	77.2	68.0	41.0	60.3	54.99	1.73
T_7, N_{20} + N_{20} + N_{40}	88.4	82.0	47.9	58.5	60.26	1.98
T_8, N_{40} + N_{20}+ N_{20}	81.9	78.8	43.9	59.4	57.46	1.83
T_9, N_{40}+ N_{40}	50.2	34.3	22.0	64.1	37.80	1.37
T_{10}, N_{20} + N_{20}+ N_{20} + N_{20}	68.2	56.7	35.7	63.0	49.73	1.57
Farmers' practice*	28.4	28.0	20.8	74.2	23.94	1.13
SEm±	1.9					
CD (P=0.05)	5.7					
Experiment 2						
T_1, No-N control	28.3				20.46	1.10
T_2, N_{80}	64.4	45.2	33.7	74.4	51.93	1.72
T_3, N_{120}	84.2	46.6	31.6	67.9	63.61	1.77
T_4, N_{160}	100.2	45.0	27.7	61.8	70.60	1.80
T_5, $FYM_{2.5t}$+N_{80}	81.3	66.3	38.7	58.3	62.95	1.89
T_6, $FYM_{2.5t}$+N_{120}	96.9	57.2	33.3	58.2	65.68	1.68
T_7, $FYM_{2.5t}$+N_{160}	111.3	51.9	29.3	54.8	72.91	1.65
T_8, NCU-N_{120}	105.1	64.1	36.6	57.1	69.85	1.81
T_9, Farmers' practice$	45.4	37.8	32.3	77.5	33.64	1.38
SEm±	2.0					
CD (P=0.05)	5.9					

RE - Recovery efficiency; AE = agronomic efficiency (kg grain/kg N applied); PE = production efficiency (kg grain/kg N uptake)
*Farmers' practice: FYM @ 5 t/ha = 20 kg N/ha; $Farmers' practice: FYM @ 5t/ha + DAP @ 40 kg/ha= 40 kg N/ha

10 days after transplanting + ¼ N at maximum tillering + ½ N at panicle initiation stage could be recommended for optimizing the rice production and productivity in mid-hill acidic soils of Sikkim.

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