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IMPACTS OF SPLIT APPLICATION OF ORGANIC FERTILIZER ON NITROGEN UPTAKE AND USE EFFICIENCY IN DIRECT-SEEDED RICE

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Abstract

Improved nitrogen fertilizer management in organic rice cultivation improves nitrogen use efficiency, lowering N losses and, ultimately reducing environmental deterioration. A field experiment was conducted to assess the impact of twice-split organic nutrient management strategy on N absorption and nitrogen use efficiencies (NUE) in direct seeded rice production (DSR) system. The N absorption pattern estimated through logistic model showed that the fast N uptake time with VC100 was considerably longer than that of CF100. Synchronization of soil available N and crop N demand for a longer duration during the fast N uptake phase, vermi compost (VC) applied in twice-splits increased N uptake, dry matter production, yield characteristics and grain yield compared to CF100.It was concluded that VC applied in twice, *i.e.,* basal fertilizer and top dressing at 5 days before panicle initiation was as effective as CF100 in enhancing NUE of DSR in lateritic soil.

Introduction

Rice is staple food for more than 50% of the current world's human population, supplying 20% of dietary energy. In recent years, due to increased awareness of the negative impacts of excessive agrochemicals usage in conventional farming (Blankson *et al.* 2016, Elahi *et al.* 2019), the rice growing area under organic farming has expanded considerably. According to multiple research studies, rice is the highest-yielding cereal crop under organic farming, producing upto 94% of the yield achieved in conventional farming systems (Tomek *et al.* 2012) and thus profitable for growers. For higher rice productivity, higher levels of nitrogen is necessary (Robertson and Vitousek 2019). Concurrently, N is more prone to large losses following soil application due to leaching, denitrification, volatilization, and other processes resulting in serious soil and water pollutions and ultimately environmental deterioration (Fesenfeld *et al.* 2018). Higher NUE was attained in conventional farming by providing N in splits through synthetic chemical fertilizers at critical crop growth stages to meet crop N need, which encourages higher crop N uptake and as a result, higher yields. Organic fertilizers used as base fertilizer typically supply nutrients slowly over a lengthy period of time, which may not be enough to meet crop N demand, affecting crop N uptake, grain production and nitrogen use efficiency. Numerous studies demonstrated that soil N availability at the panicle initiation stage, one of the most critical for nutrients had a considerable impact on crop N uptake, yield and NUE (Ghosh *et al.* 2020, Ju *et al.* 2021). Among the various organic fertilizers, vermicompost (VC) possesses readily available macro- and micro-nutrients and the question is whether VC application during crucial N requirement periods achieves synchronization between soil N and crop N demand. The present study was carried out as a part of long-term experiment to investigate the impact of twice-splits organic fertilizer application on crop N uptake and NUE in direct seeded rice.

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Materials and Methods

During the years 2013-2014, a two-year field test was conducted at Indian Institute of Technology Kharagpur ($22^{O}19$'N latitude and $87^{O}19$'E longitude). The soil at the trial site was sandy loam. The experiment was carried out using a completely randomized block design with three replicates for each treatment. The treatments include optimal and sub-optimal nutrient treatments, where the nutrients were provided through inorganic (synthetic chemical fertilizers (CF)) and organic sources (VC, crop residue (CR), vermiwash (VW) and Azotobacter (AZ)). In optimal nutrient treatments (CF100, VC-b100, VC100 and VC50+CF50), 100 kg N, 50 kg P_2O_5 and 60 kg K_2O/ha were applied in CF100, for VC-b100 and VC100, VC @ 8.4 t/ha (100 kg N/ha) was applied and VC @ 4.2 t/ha in combination with 50 kg N, 25 kg P_2O_5 and 30 kg K_2O/ha were applied in VC50+CF50. With regards sub-optimal nutrient treatments (CF50+CR, VC50+VW, VC50+VW+AZ), for CF50+CR, 50 kg N, 25 kg P_2O_5 and 30 kg K_2O/ha in combination with soil incorporation of crop residues from the previous season, for VC50+VW, VC @ 4.2 t/ha besides vermiwash (vw:water::1:6), sprayed at every 10 days gap starting from tillering to flowering period and in VC50+VW+AZ, VC @ 4.2 t/ha in combination with vermiwash and Azotobacter @ 3.5 kg/ha as soil application. In control treatment, no fertilizer was applied. In all the VC containing treatments, except, VC-b100, the VC was applied externally in twice-splits *i.e.,* as base fertilizer and five days prior to panicle initiation stage. In CF containing treatments, entire dose of $P_2O_5$and K_2O were applied as base fertilizers. N dose was provided through urea in four equal splits *i.e.,* at basal, maximum tillering stage, five days prior to panicle initiation stage and flowering stage. The size of each plot was 20 m^2.The rice test cultivar Naveen (110 days duration) was sown during wet season (June-October) by direct seeding method at 20cm by 7.5cm spacing. The weeds were controlled by two manual hand weedings at 25 and 50 days after emergence. The experimental site's average rainfall was 1600 mm with the majority (>70%) falling during the rainy season. The harvesting of rice was done manually at physiological maturity and yields were recorded.

Rice plant samples were analyzed for leaf, stem and grain N content at maximum tillering, panicle initiation, flowering and harvest stages. The uptake of N, P and K was calculated based on nutrient concentrations and total dry matter weight. The nitrogen use efficiency (NUE) of the rice crop was calculated using the procedures of Swain *et al.*(2006) and Singh *et al.*(2012) such as agronomic N use efficiency (AE_N), nitrogen recovery efficiency (RE_N) and nitrogen harvest index (NHI).A logistic model was used to characterize the progress of crop plant N uptake in order to estimate pattern (Deng *et al.* 2018).

The nutrient management effect on nutrient content and uptake, yield, nitrogen use efficiency of direct seeded rice production system was analyzed by analysis of variance (ANOVA) test. The significance of the nutritional management was determined using F test. The least significant difference (p=0.05) for treatment mean comparison was computed for the variable showing significant effect (Gomez and Gomez1984). Moreover, Pearson's correlation coefficient was used to determine correlations between available soil N at various growth stages and rice crop yield and yield characteristics.

Results and Discussion

In both the years, the greatest N content in leaf and stem was seen in all treatments at maximum tillering stage, then fell drastically to panicle initiation and then progressively towards maturity stage. At the panicle initiation stage, leaf N content with CF100 was considerably higher than all other treatments, while statistically similar with VC100 and VC50+CF50 at the flowering stage (Fig. 1). Maximum stem N content was measured using VC-b100 at the maximum tillering stage and VC100 at the panicle initiation and flowering stages (Fig. 2). With the exception of VC100 in the first year, CF100 greatly outperformed all other treatments with regards leaf N uptake.Similarly, the largest stem N uptake was achieved with CF100, but in the second year, it

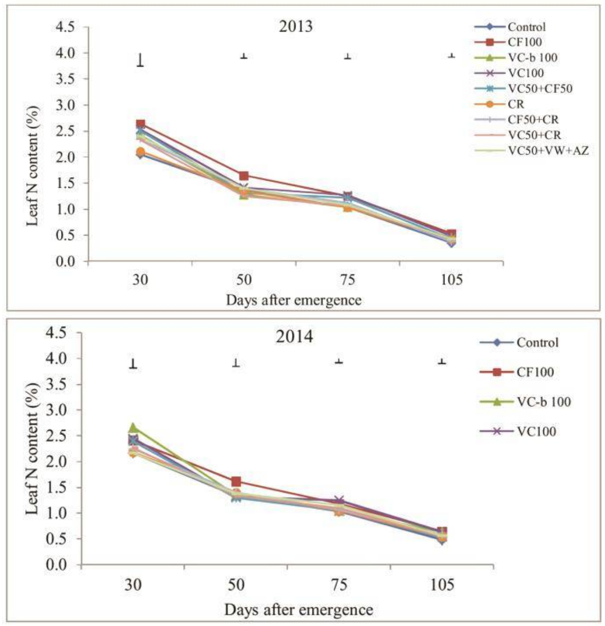

Fig.1. Leaf N content at different days after emergence of rice crop as influenced by organic and inorganic nutrients management during wet season of 2013 and 2014.

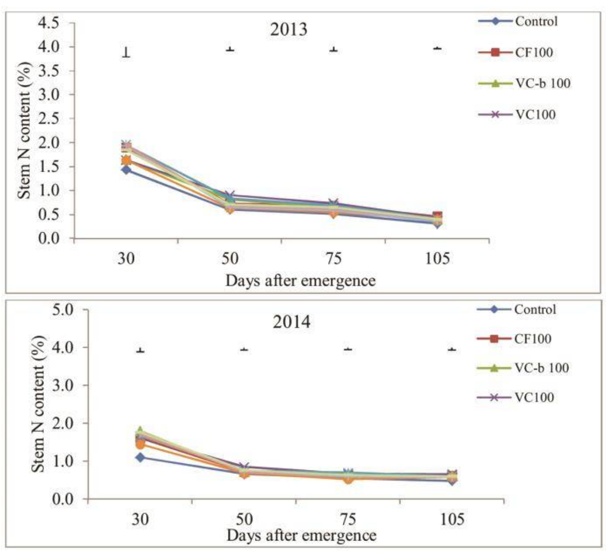

Fig. 2.Stem N content at different days after emergence of rice crop as influenced by organic and inorganic nutrients management during wet season of 2013 and 2014. The vertical lines represent least significant difference at p=0.05.

was achieved with VC100 (Table 1). VC100, which was comparable to CF100, but statistically superior to VC-b100 and VC50+CF50 in both the years, had the highest availability of soil N content. Furthermore, the soil available P content measured with VC100 was substantially higher than all other treatments. Conversely, the soil available P content of CF100 was significantly less compared to all of the VC applied optimal nutrient treatments. VC100 and CF100 were statistically non-significant in terms of soil available K, but significantly superior to VC50+CF50 in both the years (Table 2). Total N uptake was significantly higher with CF100 (104.2 and 102.5 kg/ha in 2013 and 2014, respectively) (Table 1), followed by VC100 (93.1 kg/ha in 2013 and 95.2 kg/ha in 2014) which was significantly superior to VC50+CF50 (83.8 kg/ha in 2013 and 85.4 kg/ha in 2014) and VC-b100 (73.5 kg/ha in 2013 and 83.4 kg/ha in 2014). The VC100 had an average rate of 2.34 and 2.17 kg/ha/day and an uptake duration of 25.2 and 27.7 days during fast N uptake phase in 2013 and 2014, respectively. During 2013 and 2014, the VC100 had a 58 and 78% greater average N uptake rate than VC-b100, respectively, but was 11.5 and 2.2% lower than CF100. Interestingly, the VC100's fast N uptake durations were 7.6 and 13.1 days longer than CF100's (Table 3).

Table 1. Influence of organic and chemical fertilizers on nitrogen uptake by rice plant parts at maturity during wet season of 2013 and 2014.

Nutrients management	Leaf N uptake (kg/ha)	Stem N uptake (kg/ha)	Grain N uptake (kg/ha)	Total N uptake (kg/ha)	Grain yield (kg/ha)
2013					
Control	1.7	2.7	9.8	14.1	1067
CF100	12.2	21.1	70.9	104.2	6083
VC-b100	8.6	18.5	46.5	73.5	4200
VC100	10.3	18.4	64.5	93.1	5340
VC50+CF50	9.7	16.4	57.8	83.8	5297
CR	4.1	6.5	23.0	33.5	2413
CF50+CR	8.1	13.9	50.7	72.7	4907
VC50+CR	5.4	9.6	35.5	50.5	3213
VC50+VW+AZ	5.7	9.3	37.2	52.3	3167
S Em (±)	0.7	1.3	2.8	3.1	199
LSD (p=0.05)	2.1	3.8	8.5	9.2	597
2014					
Control	2.3	3.4	10.4	16.1	1093
CF100	13.8	22.5	66.2	102.5	5767
VC-b100	11.8	23.1	49.4	83.4	4563
VC100	12.9	24.9	58.3	95.2	5140
VC50+CF50	11.5	20.3	54.2	85.4	5153
CR	5.1	7.9	20.6	33.5	2160
CF50+CR	10.6	18.1	50.1	78.3	4690
VC50+CR	8.4	12.9	37.7	58.7	3320
VC50+VW+AZ	8.0	12.8	34.1	54.6	3113
S Em (±)	0.7	1.1	1.9	2.9	183
LSD (p=0.05)	2.2	3.4	5.7	8.9	547

VC applied in twice-splits had significantly greater available soil N and P concentrations than CF100 during flowering stage (Table 2). This was most likely due to incorporation of C into soil through VC, which enhanced soil microbial population, which expedited N transformation and P solubilization processes in soil, resulting in higher N and P uptake. Furthermore, a substantial positive association between available soil N at panicle initiation and flowering stages and leaf and stem N contents at respective stages suggests that higher soil nutrient availability led to higher N uptake. Increased N absorption most likely led to increased dry matter build up and maximum tiller production, as well as yield parameters such as panicle number, filled grains per panicle and test weight. Moreover, findings revealed a significant positive association between the available soil N and above ground biomass accumulation at critical stages, panicle and grain N content, yield attributes, grain and straw yields. This could be explained by increased N availability at critical stages, which could have boosted N transformation related enzymes in leaves.

Table 2. Effects of organic and chemical fertilizers on soil available N, P and K content at flowering stage of rice during wet season of 2013 and 2014.

Nutrients management	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
		2013			**2014**	
Control	134.4	22.5	87.3	126.4	24.1	86.1
CF100	175.2	26.6	117.6	175.5	28.2	121.7
VC-b100	161.3	32.5	113.1	158.1	32.2	115.7
VC100	191.1	34.5	119.8	184.8	35.3	120.8
VC50+CF50	164.3	31.6	108.6	168.9	31.2	104.5
CR	137.4	27.2	90.3	131.1	26.8	91.4
CF50+CR	148.3	26.4	101.5	165.3	26.2	101.1
VC50+CR	156.1	26.7	95.0	166.6	27.4	103.8
VC50+VW+AZ	150.8	26.8	97.8	168.6	26.4	104.3
S Em ($\pm$)	6.5	0.4	2.0	5.3	0.6	2.3
LSD (p=0.05)	19.4	1.1	5.9	15.8	1.9	7.0

The decline in dry matter and yield under the full-dose N treatment, VC-b100, could be attributable to the reason that the younger rice plants were unable to absorb considerable portion of the available soil N, resulting in losses. Rice plants were better able to assimilate available nitrogen at later phases of growth, resulting in lower nitrogen losses. Findings showed that VC application in twice-splits aided rice plant N absorption by ensuring N availability for a longer period of time during the fast N uptake phase (Table 3). Further, there was a substantial positive correlation between available soil N and grain N, P and K uptake which was attributed to availability of higher soil, N, P and K concentrations (Table 2), which favoured more root growth, leaf area, increased availability of metabolic energy for ion uptake and synthesis of carriers responsible for transport of ions across membranes. Kyi *et al.* (2019) discovered a favourable relationship between available soil nutrients and their uptake. This revealed that twice-splits applications of organic fertilizer (VC) to the direct seeded rice production system enhanced soil total N status while maintaining sustainable production in lateritic soil.

Among the optimal nutritional treatments CF100 had a substantially higher AE_N than VC-b100 in both the years, but was statistically equal to VC100 and VC50+CF50.In both the years, the AE_N of CF50+CR (50.7kg/kg) was greater than that of VC50+CR (42.3 kg/kg)(Table 4). In general, adequate nutrient treatments resulted in increased RE_N when compared to sub-optimal nutrient treatments. CF100 had the highest RE_N (0.9 kg/kg), which was considerably better than VC-b100 (0.59 kg/kg in 2013 and 0.7 kg/kg in 2014) in both the years, but did not differ statistically from VC100 in 2013 or VC100 and VC50+CF50 in 2014. The effect of optimal and sub-optimal nutrient treatments on rice NHI was not significant in the first year, but it became significant in the second.CF100 and VC50+CF50 were statistically at par with VC100 for the NHI in the first year, but were significantly superior to VC-b100 in the second year.

Table 3. Logistic equation characteristics of N uptake by rice plants subjected to organic and chemical fertilizers in 2013 and 2014.

Nutrients management	Regression equation	R^2	t_1(DAS)	t_2 (DAS)	T (d)	V_t (kg/ha/day)
2013						
Control	$N=16.6/(1+1.72e^{-0.0569t})$	0.905*	43.6	62.7	19.1	0.19
CF100	$N=115.8/(1+4.73e^{-0.1490t})$	0.651*	31.6	49.2	17.6	3.78
VC-b100	$N=81.9/(1+2.72e^{-0.1480t})$	0.599*	32.1	45.7	13.6	2.74
VC100	$N=103.5/(1+3.93e^{-0.1044t})$	0.782*	30.5	55.7	25.2	2.34
VC50+CF50	$N=92.3/(1+3.81e^{-0.0945t})$	0.818*	30.2	58.1	27.9	1.91
CR	$N=36.0/(1+3.93e^{-0.0815t})$	0.875*	30.6	62.9	32.3	0.64
CF50+CR	$N=78.7/(1+4.71e^{-0.1112t})$	0.774*	32.1	55.8	23.7	1.92
VC50+CR	$N=55.8/(1+3.13e^{-0.0421t})$	0.989*	34.2	88.4	54.2	0.65
VC50+VW+AZ	$N=56.3/(1+2.70e^{-0.0874t})$	0.813*	33.7	56.4	22.7	1.11
2014						
Control	$N=16.9/(1+1.73e^{-0.0446t})$	0.957*	47.2	71.8	24.6	0.16
CF100	$N=103.2/(1+4.38e^{-0.1800t})$	0.567*	30.9	45.5	14.6	4.07
VC-b100	$N=84.8/(1+2.34e^{-0.1599t})$	0.555*	32.9	43.6	10.7	3.05
VC100	$N=104.1/(1+4.00e^{-0.0951t})$	0.821*	30.7	58.4	27.7	2.17
VC50+CF50	$N=90.1/(1+4.01e^{-0.1274t})$	0.701*	30.6	51.2	20.6	2.51
CR	$N=36.7/(1+3.53e^{-0.0913t})$	0.824*	30.6	58.2	27.6	0.74
CF50+CR	$N=77.5/(1+4.54e^{-0.1780t})$	0.575*	31.1	77.9	46.8	1.30
VC50+CR	$N=58.7/(1+3.48e^{-0.0976t})$	0.796*	30.7	56.3	25.6	1.27
VC50+VW+AZ	$N=58.7/(1+3.38e^{-0.0924t})$	0.815*	31.1	57.4	26.3	1.21

The present findings revealed that the maximum soil N concentration resulted in increased above-ground biomass, grain yield and N absorption, hence resulting in higher AE_N, RE_N and NHI of rice with optimal nutrient treatments compared to sub-optimal nutrient treatments. Increasing the availability of N by applying VC twice in the optimal nutrient treatment (VC100), improved the synchronicity between soil N supply and crop N demand, resulting in higher grain yield, above-ground biomass build up, and N uptake, as well as higher AE_N, RE_N and NHI as in CF100. However, compared to CF100, applying VC full-dose as a base fertilizer (VC-b100) resulted in poor grain yield and nutrient absorption resulting in lower AE_N and RE_N as compared to VC100. The entire use of VC as a base fertilizer could have led to higher N losses and, as a result, lower N utilization in the rice crop (Bhattacharya *et al.* 2006). Rice plants mostly take up N in the form of NH_4^+-N (Myint *et al.* 2010), and NO_3^--N is more susceptible to leaching losses during nitrification (Dobermann and Fairhurst 2000). In comparison to its twice-splits application treatment, applying the whole dose of VC at sowing time likely increased the nitrification of NH_4^+-N to NO_3^--N, resulting in more N loss (Kumar *et al.* 2018). The highest physiological N use efficiency was achieved with VC-b100, indicating that using the entire dose of VC as base fertilizer could significantly increase above-ground biomass during maximum tillering stage, resulting in higher straw yield and physiological N use efficiency. In contrast, the soil N stress during later growth stages had an impact on rice crop yield characteristics and grain yield, and hence AE_N and RE_N. CF50+CR exhibited the highest AE_N and RE_N, which was higher than VC-b100, among the several sub-optimal nutrition treatments. The high NUE of CF50+CR was attributed to twice-splits application of inorganic fertilizer at critical growth stages in smaller doses that could match crop N demand under improved soil health through crop residue recycling, which enhanced grain yield and N absorption, and hence the NUE. Similar findings of enhanced NUE as well as reduced N volatalization losses with manure application in wheat-rice production system was reported by Delei *et al.* (2021). The decreased AE_N of VC-b100 compared to VC100 was ascribed to the crop's inefficient use of nitrogen, as indicated by the rice-chickpea production system's much lower REY. Significantly higher AE_N and RE_N were noted with 'CF50+CR' among the sub-optimal nutrition treatments, which was attributed to efficient N utilisation through regular incorporation of previous crop residue in combination with synthetic chemical fertilizers in twice-splits in lower quantities at critical stages of rice in the production system. This clearly shows that applying appropriate nutrients to rice crop in twice-splits using organic/synthetic chemical fertilizers resulted in efficient N translocation to sinks such as rice grain in the production system.

Table 4. Effects of organic and inorganic nutrients management on various agronomic N use efficiencies (AE_N, PE_N, IE_N, NHI and RE_N) in rice during wet season of 2013 and 2014.

Nutrients management	AE_N (kg/kg)	PE_N (kg/kg)	IE_N (kg/kg)	NHI	RE_N (kg/kg)
2013					
Control	-	164.0	75.7	0.69	-
CF100	50.2	118.9	58.3	0.68	0.90
VC-b100	31.3	138.0	57.3	0.64	0.59
VC100	42.7	125.2	57.6	0.69	0.79
VC50+CF50	42.3	136.2	63.4	0.69	0.70
CF50+CR	50.7	147.5	67.5	0.70	0.77
VC50+CR	28.5	135.3	63.6	0.70	0.48
VC50+VW+AZ	26.3	127.8	60.7	0.71	0.48
S Em (±)	4.2	4.9	2.6	0.3	0.04
LSD (p=0.05)	12.6	14.8	7.8	NS	0.11
2014					
Control	-	153.3	68.2	0.65	-
CF100	46.7	114.4	56.2	0.64	0.86
VC-b100	34.7	127.8	54.7	0.59	0.67
VC100	40.5	119.6	54.0	0.61	0.79
VC50+CF50	40.6	130.4	60.6	0.64	0.69
CF50+CR	49.6	128.3	60.0	0.64	0.86
VC50+CR	33.9	126.4	56.5	0.64	0.65
VC50+VW+AZ	25.3	128.9	57.0	0.63	0.48
S Em (±)	3.6	3.9	1.3	0.1	0.06
LSD (p=0.05)	10.7	11.8	3.8	0.3	0.18

It can be concluded that the nutrient management treatments had a notable impact on the NUE in rice production system. Except for VC-b100, all of the optimal nutrient treatments were comparable in terms of AE_N and NHI of rice crop. In comparison to CF100, the AE_N, RE_N and NHI of rice were much reduced with VC-b100. Furthermore, when compared to CF100 or VC100, the VC-b100 produced significantly reduced AE_N and NHI in the rice production system during both the years. Thus, on lateritic soils, twice-splits application of organic fertilizer (VC) 5 days prior to rice panicle initiation was effective in enhancing NUE of the directed seeded rice.

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