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Split application of vermicompost to rice (*Oryza sativa* L.): its effect on productivity, yield components, and N dynamics

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Abstract Organic agriculture is gaining a gradual momentum across the world for improving nutritional quality of food, restoring soil health, generating rural economy, and creating better environmental conditions. Organic agriculture can foster sustainability in subhumid tropical soils low in organic carbon. Nutrient use efficiency of basal soil application of vermicompost is very low. Thus, this study was aimed to test whether nitrogen use efficiency (NUE) and crop yield can be enhanced by split application of vermicompost. There is no published information on split application of vermicompost (VC) in rainfed rice. An experiment with rice (cv. Pankaj) was conducted on loam soil in Giridih, India, during 2008 and 2009. Vermicompost, a rich source of readily available nutrients, has high microbial activity and contains growth hormones. Study comprises one of three split applications of vermicompost at different growth stages of rice (i.e., maximum tillering, panicle initiation, and flower). Split application of vermicompost resulted higher yield parameters such as panicles (294 m^{-2}), filled grains per panicle (138), and total spikelets per panicle (142), grain yield (3.91 t ha^{-1}), and NUE, but only if vermicompost was applied at two or three doses. Higher availability of nitrogen (N) in soil with split applications coincides with higher NUE, and thus, split application not promoted N losses. Split application of vermicompost enhances the sustainability of rice cropping system.

Keywords Split application · Vermicompost · Rice · N dynamics

Introduction

Rice (*Oryza sativa* L.) is a staple food crop for a large proportion of the world's population, and its demand is accelerating with the increasing population (Bezbaruha et al. 2011). Best practice nutrient management in cropping systems is characterized by the application of nutrients (no matter what the source: organic and/or inorganic) in the right quantities, in the right form, at the right time, and in the right place (Vaarst 2010). The mineralization of organic nitrogen (N) is a key process in determining the effectiveness of N nutrition for rice. Thus, improved understanding of both N dynamics in soil and its uptake by crops is necessary to improve nutrient use efficiency (Gastal and Lemaire 2002). Organic manures are usually applied during land preparation because their nutrient transformation/mineralization process is very slow. Crop response to organic manures depends on both the type and quality of manure (Tandon 1992). Vermicompost is rich in nutrients (Gandhi et al. 1997) and microbial activity (Edwards 1998) and contains growth hormones (Nielson 1985). All nutrients in vermicompost are in a readily available form, thereby enhancing uptake of nutrients by plants and, in turn, crop

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yield (Banik and Sharma 2009; Bejbaruha et al. 2009; Sreenivas et al. 2000; Jadhav et al. 1997). Vermicompost can be used alone for organic farming and as a component of integrated nutrient management for rice production (Banik and Sharma 2009; Bejbaruha et al. 2009, 2011). The nutrient use efficiency (NUE) of organic manures applied in basal dressings is quite low usually ranging from 5 to 20 % (Manivannam and Sriramchandrasekharan 2009; Myint et al. 2010). In order to increase crop yield and NUE, it has been recommended that fertilizer N is applied in split doses at different critical growth stages of a crop (Perez et al. 1996; Peng et al. 2010). Thus, this study aimed to test whether NUE and crop yield can be enhanced by split applications of vermicompost.

Materials and methods

Experimental site and soil

Experiments were conducted with rice (cv. Pankaj) under rainfed conditions during the wet season (June–September) in 2008 and 2009 at the Agricultural Experimental Farm of the Indian Statistical Institute, Giridih, India. The farm is located in the eastern plateau region (24° 1′ 30″ N latitude; 80° 31′ 15″ E longitude) at an elevation of 276 m above mean sea level with an average slope of 2 %. The climate is subhumid with an average annual rainfall of 1,343 mm and average maximum and minimum temperatures of 23.8 and 16.8 °C, respectively. The relative humidity ranges from 78 to 95 %, and the mean annual evapotranspiration is 1,293 mm. The soil is an Oxisol with a loam texture (26.3 % clay, 42 % sand, and 31.7 % silt). The physicochemical properties of the soil (0–20 cm) determined by standard methods (Jackson 1973) were the following: pH 5.7, 0.43 % organic C, 0.04 % total N, 13.8 kg ha^{-1} available P, and 138 kg ha^{-1} available K.

Experimental treatments and field operations

Five treatments were compared in plots measuring 5× 5 m arranged in a randomized block design with each treatment replicated four times. The treatments, except the absolute control (T_1), were supplemented with vermicompost (VC) to supply 120 kg N ha^{-1} as follows: full basal (T_2), 1/2 basal+1/2 at maximum tillering (MT) stage (T_3), 1/3 basal+1/3 at MT stage+1/3 at panicle initiation (PI) stage (T_4), and 1/3 basal+1/3 at MT stage+1/6 at PI stage+1/6 at flowering stage (T_5). Vermicompost contained 1.7 % N, 0.7 % P_2O_5, and 0.86 % K_2O. Three seedlings (20–23 days old) were transplanted per hill with a plant-to-plant spacing of 15 cm and row-to-row spacing of 20 cm. Transplanting was done on 14 and 18 July and harvesting on 13 and 16 November in 2008 and 2009, respectively. The crop was weeded twice manually. There was no pest control used as major insect pest incidence was not noticed.

Preparation of vermicompost

Six biodegradable organic wastes (BOWs) were used for the preparation of vermicompost, viz., cow dung, municipal solid waste, aquatic weeds such as common duckweed (*Lemna minor* L.), water hyacinth (*Eichhornia crassipes*), Bermuda grass (*Cynodon dactylon*), fly ash (effluent from thermal power plant), and kitchen waste. Adult earthworms (*Eisenia fetida*), suitable for this subtropical climate, were inoculated at the rate of 15 worms per kg of biodegradable waste (Edwards 1998). The materials were incubated for 50 days. During vermicomposting, watering was done with the help of a sprinkler as and when required to moisten the BOWs. The feed material was converted into loose granular mounds as a result of passing through the alimentary canal of the earthworms. All material was collected, and two pyramidal heaps were made. After a day, a heap was slowly brushed aside, and adult earthworms were collected. The compost was dried in the shade for 2 days and sieved (4 mm mesh) to separate cocoons. Samples (100 g) were collected for chemical analysis of nutrients in the laboratory. Organic carbon was estimated using the method described by Walkley and Black (1934). Total nitrogen, total phosphorus, total potassium, and micronutrients were estimated by adapting a method described by Jackson (1973).

Yield and yield components

Plant height (10 randomly selected hills) and panicles per square meter area were recorded at harvest. From the harvested area, 10 panicles were randomly selected to record numbers of spikelets and filled grains per panicle. Straw and grain yields were recorded on a plot basis by leaving two border rows. Grain yield is reported at 14 % moisture content.

Plant and soil chemical analyses

Grain and straw were separated, oven dried (at 60 °C for 48 h), ground, and stored in a desiccator. To determine total N, samples were digested in a triacid mixture ($H_2SO_4/HClO_4/HNO_3$ at a ratio of 1:3:10) with $CuSO_4$ and distilled in the semi-micro Kjeldahl apparatus (Jackson 1973). Inorganic N (NH_4–N and NO_3–N) was determined using the direct distillation method (Keeney and Bremner 1966) from soil samples (0–20 cm depth) collected at 25, 50, 75, and 90 days after transplanting (DAT).

N use efficiency

Taking into account the grain yield and total N uptake, the apparent N recovery (ANR) (Westerman and Kurtz 1974) and agronomic N efficiency (ANE) (Dobermann and Fairhurst 2000) were calculated using the following equations:

$$\mathrm{ANE}(\mathrm{kg\,grain/kg\,N\,applied}) = (\mathrm{Yt}-\mathrm{Yo})/\mathrm{Na}$$
$$\mathrm{ANR}\ (\%) = [(\mathrm{Ut}-\mathrm{Uo})/\times 100]\ /\ \mathrm{Na}$$

where Yt is the grain yield in the test treatment (kilogram per hectare), Yo is the grain yield in the control plot (kilogram per hectare), Ut is the uptake of N in the test treatment (kilogram per hectare), Uo is the uptake of N in the control plot (kilogram per hectare), and Na is the nitrogen applied.

Statistical analysis

Data were analyzed using SPSS statistical software (ver 11.0; StatSoft, USA). Analysis of variance (ANOVA) was used to determine treatment effects at 5 % confidence level for their significance by Duncan's multiple range test (DMRT) (Cochran and Cox 1992).

Results

Yield and yield components of rice

The yield components, except plant height, were significantly increased by application of VC (Table 1). Split application of VC increased the number of panicles compared with the basal application (T_2) with no difference between the different split applications (T_3, T_4, T_5). A similar trend was noted for filled grains per panicle, but there were no significant differences between the VC treatments in the total spikelets per panicle, but all VC treatments were significantly higher than the control (Table 1). The VC-treated plots had significantly higher yield of rice straw than the control plots (Table 2). Application of VC increased the grain yield of rice compared with the control; yield was significantly higher in T_5 compared with the basal application, although it was not significantly different from T_4 and T_3 (Table 2). A four-split application (T_5) had 142 and 32 % more grain yield than T_1 and T_2, respectively.

Nitrogen uptake, apparent N recovery, and agronomic efficiency

As nitrogen uptake by a crop is a function of total biomass production and percent N content in the biomass (straw and grain), N uptake followed a similar pattern to that observed with grain yield (Table 2) with the highest N uptake in T_5 (69 kg ha^{-1}). ANE and ANR increased as the number of splits in VC application increased (Table 2). With the basal application of VC,

Table 1 Average yield attributing characters of rice under different treatments during 2 years (2008–2009)

Treatment	Plant height (cm)	No. of panicles (m^{-2})	No. of filled grains per panicle	Total spikelets per panicle	Test weight (g)
T_1	102 a	174 d	87 d	96 b	19.2 b
T_2	105 a	237 c	112 c	128 a	20.3 ab
T_3	109 a	248 ab	119 bc	131 a	20.7 a
T_4	107 a	251 ab	127 ab	138 a	20.5 ab
T_5	104 a	264 a	138 a	142 a	20.7 a

Treatments with the same letters are not significantly different at $P<0.05$. T_1, absolute control; T_2, full dose of vermicompost as basal (equivalent 120 kg N ha^{-1}); T_3, 1/2 basal+1/2 at MT stage; T_4, 1/3 basal+1/3 at MT stage+1/3 at PI stage; T_5, 1/3 basal+1/3 at MT stage+1/6 at PI stage+1/6 at flowering stage

Table 2 Average rice straw and grain yields and N use efficiencies under different treatments during 2 years (2008–2009)

Treatment	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	Apparent N recovery (%)	Agronomic efficiency (kg grain kg N^{-1})
T_1	2.15 b	1.61 c	42.1 d	–	–
T_2	3.70 a	2.96 b	60.4 c	30.5	22.5
T_3	3.94 a	3.18 ab	62.3 bc	33.7	26.2
T_4	4.17 a	3.45 ab	65.7 ab	39.3	30.7
T_5	4.65 a	3.91 a	69.0 a	44.8	38.3

Treatments with the same letters are not significantly different at $P<0.05$. T_1, absolute control; T_2, full dose of vermicompost as basal (equivalent 120 kg N ha^{-1}); T_3, 1/2 basal+1/2 at MT stage; T_4, 1/3 basal+1/3 at MT stage+1/3 at PI stage; T_5, 1/3 basal+1/3 at MT stage+1/6 at PI stage+1/6 at flowering stage

an ANE 22.5 kg of grain per kg of applied nitrogen was found, and this increased maximum ANE of 38.3 kg of grain per kg of applied nitrogen was recorded due to a four-split application of VC (Table 2).

NH_4–N concentrations in the soil were higher than NO_3–N concentrations in all sampling dates (Table 3). Both forms of mineral N were significantly higher in all the VC-treated plots than in the control. When the N was applied in a basal application of VC (T_2), mineral nitrogen was higher at 25 DAT and then declined over the period of time. Where VC was applied as split applications, mineral N content in soil increased up to 50 DAT and declined thereafter, but still maintained higher mineral N concentrations at 75 and 90 DAT than those in T_2 (Table 3).

Discussion

Increasing the availability of N through split application of VC seems to have increased the synchrony of N supply and demand and therefore increased the N uptake (Bhattacharyya et al. 2006; Dobermann and Fairhurst 2000). Following repeated applications of VC, mineral N concentrations in the soil can be maintained through sustained mineralization of organic N (Manivannan and Sriramachandrasekharan 2009; Kale et al. 1992). Lower ANE and ANR with the basal application of VC may be a result of greater nutrient losses or inefficient utilization of nutrient (Bhattacharyya et al. 2006; Kale et al. 1992). Rice plants take up nitrogen in the NH_4 form (Myint et al. 2010); when nitrification occurs, the NO_3 form of N is more prone to losses by leaching (Dobermann and Fairhurst 2000).

By splitting applications of VC, nutrient supply is better matched with plant demand throughout the crop growth period, increasing the yield components and grain yield (San-oh et al. 2008; Bhattacharyya et al. 2006). In rice, the main yield determinants have been identified as follows: (a) leaf area and shape to maximize photosynthetic efficiency, (b) a well-developed deep root system, (c) high leaf area index at

Table 3 Nitrogen (milligram per kilogram) dynamics at different days after transplanting (DAT) due to vermicompost application (2 years pooled data)

Treatment	25 DAT		50 DAT		75 DAT		90 DAT	
	NO_3–N	NH_4–N	NO_3–N	NH_4–N	NO_3–N	NH_4–N	NO_3–N	NH_4–N
T_1	5.7 c	11.2 d	3.7 b	9.2 b	4.2 c	6.2 c	3.1 c	4.7 c
T_2	12.8 a	33.8 a	9.3 a	22.9 ab	7.6 b	14.5 b	8.2 b	12.3 b
T_3	9.7 b	22.6 b	11.7 a	30.2 a	9.8 ab	20.9 a	10.3 a	16.7 a
T_4	7.3 bc	18.5 c	10.8 a	26.5 a	10.2 ab	20.8 a	10.8 a	18.1 a
T_5	8.6 b	17.9 c	10.3 a	24.8 ab	11.1 ab	21.3 a	12.1 a	18.6 a

Treatments with the same letters are not significantly different at $P<0.05$. T_1, absolute control; T_2, full dose of vermicompost as basal (equivalent 120 kg N ha^{-1}); T_3, 1/2 basal+1/2 at MT stage; T_4, 1/3 basal+1/3 at MT stage+1/3 at PI stage; T_5, 1/3 basal+1/3 at MT stage+1/6 at PI stage+1/6 at flowering stage flowering, and (d) higher crop growth rate during PI. Yield components such as the number of productive tillers, spikelets per panicle, and grain weight are also considered to contribute largely to the yield (Bhandari et al. 2002). Rice requires a sustained nutrient supply until its reproductive stage (Murali et al. 2007). Consequently, synchronized nutrient supply increases the efficiency of the translocation of photosynthates to sink (grains), resulting in more filled grains as indicated by the data collected here. Grain weight is a genetically controlled trait; therefore, agronomic manipulation of this component is limited. Crop yield (grain and straw) is a function of several yield determinants. There is some indication of increased rice yield with the split application of vermicompost, though the impact was less than that observed by Dobermann et al. (2000) with split application of N fertilizers.

Conclusion

The nutrient use efficiency (NUE) of organic manures applied in basal dressings may be able to be improved by split applications during the crop-growing period. However, the effectiveness of such approaches will depend on whether the manure can be readily incorporated in the presence of a growing crop and whether it contains some readily available nitrogen which is released immediately on application. More work is needed to develop appropriate locally adapted strategies for nutrient management in organic farming systems. The labor requirements of split applications should also be taken into account in planning any nutrient management strategy. Where high NUE is achieved with high labor requirements, overall system efficiency and profitability may not be improved.

References

Banik P, Sharma RC (2009) Effect of organic and inorganic sources of nutrients on the winter crops-rice based cropping systems in sub-humid tropics of India. Arch Agron Soil Sci 55:285–294

Bejbaruha R, Sharma RC, Banik P (2009) Direct and residual effect of organic and inorganic source of nutrients on rice based cropping systems in sub-humid tropics of India. J Sustain Agric 33:674–689

Bezbaruha R, Sharma RC, Banik P (2011) Effect of nutrient management and planting geometry on productivity of hybrid rice (*Oryza sativa* L.) cultivars. Am J Plant Sci 2: 297–302

Bhandari AL, Ladha JK, Pathak H, Padre AT, Dawe D, Gupta RK (2002) Yield and soil nutrient changes in a long-term rice-wheat rotation in India. Soil Sci Soc Am J 66:162–170

Bhattacharyya R, Sachdev MS, Uppal KS, Narayanaswamy G, Datta SP, Singh AK (2006) Effect of nitrogen N 15-labeled urea application alone and in combination with FYM and green manure on yield and nitrogen use efficiency by rice. J Indian Soc Soil Sci 54:500–504

Cochran WG, Cox GM (1992) Experimental designs. Wiley, New York

Dobermann A, Fairhurst TH (2000) Rice: nutrient disorders and nutrient management. Potash and Phosphate Institute of Canada (PPIC) and IRRI, Norcross.

Dobermann A, Dawe D, Roetter RP, Cassman KG (2000) Reversal of rice yield decline in a long-continuous cropping experiment. Agron J 92:633–643

Edwards CA (1998) Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: Edwards CA (ed) Earthworm ecology. CRC, Boca Raton, pp 292–300

Gandhi M, Sangwan V, Kapoor KK, Dilbaghi N (1997) Composting of household wastes with and without earthworms. Environ Ecol 15:432–434

Gastal F, Lemaire G (2002) N uptake distribution in crops: an agronomical and ecophysiological perspective. J Exp Bot 53: 789–799

Jackson ML (1973) Soil chemical analysis. Prentice-Hall of India, New Delhi

Jadhav AD, Talashilkar SC, Pawar AG (1997) Influence of the conjunctive use of FYM, vermicompost and urea on growth and nutrient uptake in rice. J Maharashtra Agric Univ 22: 249–250

Kale RD, Mallesh BG, Bano K, Bagyaraj DJ (1992) Influence of vermicompost application on the available macro-nutrients and selected microbial population in a paddy field. Soil Biol Biochem 24:1317–1320

Keeney DR, Bremner TM (1966) Exchangeable NH_4, NO_3 and NO_2 by direct distillation method. Soil Sci Soc Am Proc 30: 577–582

Manivannan R, Sriramachandrasekharan MV (2009) Effect of organic sources and urea on N transformation and lowland rice grown in clay loam soil. Res J Agric Biol Sci 5:1104–1109

Murali A, Ramasamy P, Mohammad AM (2007) Impact of post panicle initiation nutrient management on the yield of rice. Res J Agric Biol Sci 3:638–641

Myint AK, Yamakawar T, Kajihara T, Myint KKM, Zenmyo T (2010) Nitrogen dynamics in a paddy field fertilized with mineral and organic nitrogen sources. American-Eurasian J Agric Environ Sci 7:221–231

Nielson RL (1985) Presence of plant growth substances in earthworm demonstrated by paper chromatography and went pea test. Nature 208:1113–1114

Peng S, Buresh RJ, Huang J, Zhong X, Zou Y, Yang J, Wang G, Liu Y, Hu R, Tang Q, Cui K, Zhong F, Dobermann A (2010) Improving nitrogen fertilization in rice by site-specific N management—a review. Agron Sustain Dev 30:649–656

Perez CM, Juliano BO, Liboo SP, Alcantara JM, Cassman KG (1996) Effects of late nitrogen fertilizer application on head rice yield, protein content, and grain quality of rice. Cereal Chem 73:556–560

San-oh Y, Kondo M, Ookawa T, Hirasawa T (2008) Ecophysiological analysis on effect of planting patter on biomass production and grain yield in rice. JARQ 42:79–89

Sreenivas C, Muralidhar S, Rao MS (2000) Vermicompost, a viable component of IPNSS in nitrogen nutrition of ridge gourd. Ann Agric Res 21:108–113

Tandon HLS (1992) Fertilizers and their integration with organics and bio-fertilizers. In: Tandon HLS (ed) Fertilizers, organic manures, recyclable wastes and bio-fertilizers, (p 32–36). Fertiliser Development Consultation Organisation, New Delhi

Vaarst M (2010) Organic farming as a development strategy: who are interested and who are not? J Sustain Develop 3:38–50

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. Soil Sci 37:29–38

Westerman RL, Kurtz LT (1974) Isotopic and non isotopic estimation of fertilizer nitrogen uptake by Sudangrass in field experiments. Soil Sci Soc Am Proc 38:107–109