Archives of Agronomy and Soil Science
Vol. 58, Issue. 8, 2012, 847-857

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Organic manure supplementation effects on rice–pulse cropping system productivity

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(*Received 25 June 2010; final version received 7 January 011*)

The effects of organic manure supplementation on rice–pulse cropping system productivity were studied. Three pulses, viz., blackgram, greengram and pea were grown after rice on the same plots to explore the feasibility of growing second crops with carry-over residual soil moisture and residual soil fertility. The study revealed that during the rainy season, 30–35% higher rice grain yield was obtained when both inorganic and organic sources of nutrients were applied compared with the full dose of inorganic fertilizer, and the rice grain yield was 65–78% higher than obtained following farmers' practices. In the post-rainy season, pea crop recorded the highest grain yield of 490 kg ha^{-1} under the treatment combination of *Sesbania* and inorganic fertilizer. Organic carbon, and available N, P, K also enhanced yield by 20–29%, 5.0–29.4 to 7.9–39.9% and 22.4–60.3%, respectively when 25% N was applied through different organic sources of nutrients (green manure/press mud/farmyard manure).

Keywords: integrated nutrient; pulses; rainfed; rice-based cropping; residual soil moisture

Introduction

Continuous rice cultivation with only inorganic fertilizer deteriorates the soil physical properties, often resulting in declining or stagnant yields and raised concerns about the long-term sustainability of rice monoculture in different parts of the country. Inorganic nitrogen sources, when applied in combination with organics, were better utilized than inorganic nitrogen alone (Saravanan et al. 1987; Blaise et al. 2005). The integrated nutrient management was favourably reflected in the total crop yield (Rajput 1995; Haefele et al. 2003). Increased available N was also obtained with poultry manure (Mahapatra et al. 1997) and by the incorporation of organic and inorganic sources of N (Deka Medhi et al. 1996). Fertilizer N applied with organic green manures produced equivalent or even higher dry matter and N uptake than the inorganic source alone (Santra et al. 1988). Green manuring may reduce the loss of mineral N by leaching and decrease ammonia volatilization losses (Santra et al. 1988). Puste et al. (1999) found that application of 75% of the recommended dose of fertilizer (N:P:K = 60:30:30 kg ha^{-1}) along with 10 t ha^{-1} farmyard manure

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ISSN 0365-0340 print/ISSN 1476-3567 online

DOI: 10.1080/03650340.2011.554401
http://www.informaworld.com

(FYM; N:P:K = 0.5:0.2:0.45) or crop residues produced the highest grain yield (3.26 t ha^{-1}) during the rainy season and subsequently seed yield of linseed, safflower and niger during the post-rainy season. In India, Prasad et al. (2002) observed yield maximization in a rice–groundnut sequence through integrated nutrient management.

Because the type of agriculture in India is changing from subsistence to intensive cultivation, we expect that farmers will soon be in a position to apply an optimum amount of nutrients. The aim of this study was to discover: (1) the achievable benefit for farmers; (2) the impact of integrated nutrient management if farmers are able to gather 25% of nitrogen requirement from organic sources (use of sole organics like FYM or Sesbania is not possible because these require huge quantities which may not be available, for large-scale adoption these can be used along with inorganic fertilizers); (iii) the effects of nutrient management and the inclusion of legumes in the cropping system on important soil physico-chemical properties.

Bearing in mind the importance of integrated nutrient management for rice cultivation in rainfed lowland, on-farm trials were conducted on a rice–legume (pea/blackgram/greengram) cropping system.

Material and methods

An on-farm study was conducted at Dhenkanal district, Orissa, India (latitude 20°50′N to 20°55′N; longitude 85°45′E to 85°50′E, 139 masl.) during three seasons (2000–2001, 2001–2002 and 2002–2003). The region belongs to the sub-humid subtropical agro-ecological zone in which average annual rainfall is 1440 mm, with 80% of rainfall during the rainy season (June–September) due to the southwest monsoon. The mean monthly maximum temperature ranges from 46.2°C in May to 29.4°C in December. Mean monthly minimum temperature varies between 24.6°C in July and 9.0°C in December. Taxonomically, the soils of the experimental area belong to fine, loamy, mixed Hyperthermic Typic Haplaustalf. The upper layer (0–0.15 m) of the soil profile was sandy loam in texture, whereas the next two layers (0.15–0.30 m and 0.30–0.45 m) were sandy clay loam in nature. The available water ranged between 0.128 and 0.162 $m^3 m^{-3}$ at different soil depths. The bulk density was 1.55 Mg m^{-3} at 0–0.15 m soil depth and increased with depth to 1.62 Mg m^{-3} for the 0.9–1.2 m layer. The pH of the soil profile was slightly to moderately acidic (6.7) with low electrical conductivity (0.12 dS m^{-1}). The fertility status of the soil was very low.

The organic carbon, available nitrogen, phosphorous and potassium contents of organic sources of nutrients and soils (initial as well as after completion of experiments) were estimated as per the methodology described by Jackson (1967). Soil physical properties, such as porosity, bulk density, saturated hydraulic conductivity and available water capacity were measured periodically using standard procedures.

During the rainy season, a popular long-duration (145 days) rice variety in the region 'Gayatri' was transplanted with 0.20 × 0.10 m spacing and cultivated with a nutrient dose of 80:40:40 (N:P:K). The nutrient treatments consisted of, T_1, 25% N through *Sesbania* + 75% through urea; T_2, 25% N through FYM + 75% N through urea; T_3, 25% N through pressmud + 75% NPK through urea; T_4, the entire recommended dose of NPK (80:40:40) through urea only; T_5, farmers' current practice or control (depleted inorganic fertilizer dose of 30:20:20 and one time weed control). Fifty per cent of nitrogen (through organic and inorganic sources) was applied as basal at transplanting, followed by 25% inorganic nitrogen as top dressing at the tillering stage and the remaining 25% nitrogen was top dressed during the panicle initiation stage. Treatments T_1–T_4 received a uniform basal dose of 40 kg P and K per hectare in the form of single superphosphate and muriate of potash, respectively. Under farmers' practice, 20 kg ha^{-1} each of P and K was applied as basal. The nutrient management treatments in rice were imposed in a ***randomized*** block design with three replications during the rainy season and with an individual plot size of 7 × 5 m.

Green manure crop (*Sesbania rostrata*) was sown in May in a separate field, which was used as one of the organic sources of plant nutrients. Forty-five days after sowing, *Sesbania* plants were uprooted and the required quantity was incorporated into the soils of the experimental plot. Rice was transplanted 7 days after incorporation of green manure, whereas other organic manures like FYM and pressmud were applied 3 days before transplanting. The FYM used for the study contained 0.42, 0.2 and 0.4%, N, P_2O_5 and K_2O, respectively, whereas the pressmud contained 1.05, 2.1 and 1.2%, N, P_2O_5 and K_2O, respectively. The N, P_2O_5 and K_2O content of *Sesbania* was 2.9, 0.4 and 1.7%, respectively. The 25% N were applied through these sources, and P and K were adjusted accordingly by combining organic and inorganic sources of nutrients.

To explore the possibility of growing second crops after rice during the post-rainy season, three pulse crops, viz., blackgram (*Vigna mungo* L.), pea (*Pisum sativum* L.) and greengram (*Vigna radiata* (L.) Wilzek) were sownafter rice. After harvesting rice, each treatment plot was divided into three parts to grow three pulses during *rabi* season with residual fertility and carry-over soil moisture. The water use of the second crops throughout the growing period was measured and water use efficiency was determined according the following equation:

$$\text{Water use efficiency} = \frac{\text{Crop grain yield(kgha}^{-1})}{\text{Crop water use(mm)}}$$

The crop water use (*CWU*) by the second crops after rice was computed from the depletion of soil water storage in the root zone as per the following water balance equation:

$$CWU = \sum_{t1}^{t2} \Delta S \Delta t + (R + I) - DP$$

Where, *CWU* is the crop water use in mm, ΔS is the change in soil moisture storage in the root zone in mm, *R* is the rainfall in mm, *I* is the irrigation applied in mm, *DP* is the deep percolation loss in mm, and t_1 and t_2 are the start and end of growing season. Because second crops were grown with residual soil moisture only, *DP* was assumed to be zero.

To measure soil moisture depletion, soil samples were collected plotwise at depth intervals of 0–0.15, 0.15–0.30, 0.30–0.60, 0.60–0.90 and 0.90–1.20 m at the start and end of the growing season. Gravimetric moisture content was determined after oven drying the samples at 105°C for 24 h.

Crop growth attributes (dry biomass and leaf area index) of rice were measured under different nutrient management practices. Intercepted photosynthetically active radiation (IPAR) was measured by using the light transmission meter (EMS 7, Ashford, UK) and expressed in terms of percentage.

Rice equivalent yield of pulses were computed as:

$$\text{Rice equivalent yield} = \frac{\text{Quantity of particular pulse crop (kgha}^{-1}\text{)} \times \text{Cost of the pulse(Rskg}^{-1}\text{)}}{\text{Cost of rice(Rskg}^{-1}\text{)}}$$

To compute rice equivalent yield, the actual prices of rice, pea, greengram and blackgram were taken as Rs. 7.00 kg^{-1}, Rs. 24.50 kg^{-1}, Rs. 24.50 kg^{-1} and Rs. 26.25 kg^{-1}, respectively.

To calculate the standard error of mean (***SE***), least significant differences (***LSD***) and comparisons of the means by Duncan's new multiple range test STAT 9.1 were used (SAS Institute 2004).

Results and discussion

Rice growth and productivity

The study revealed that the highest above ground biomass (11.34 t ha^{-1}) was recorded under T_4 treatment (100% inorganic fertilizer) at the flowering stage, but there was no statistically significant difference from treatments T_1 (25% N through *Sesbania*) –T_3 (25% N through press mud). The lowest (10.05 t ha^{-1}) aboveground biomass was observed under farmers' management practices (T_5), which was statistically different from the other treatments at the 0.05% probability level (Figure 1). However, no significance difference in aboveground biomass was observed between treatments T_1 (25% N through *Sesbania*) and T_4 (100% inorganic fertilizer). The same trend was observed in for the leaf area index (Figure 2). The highest intercepted photosynthetically active radiation was observed in treatment T_1 (96%), which was

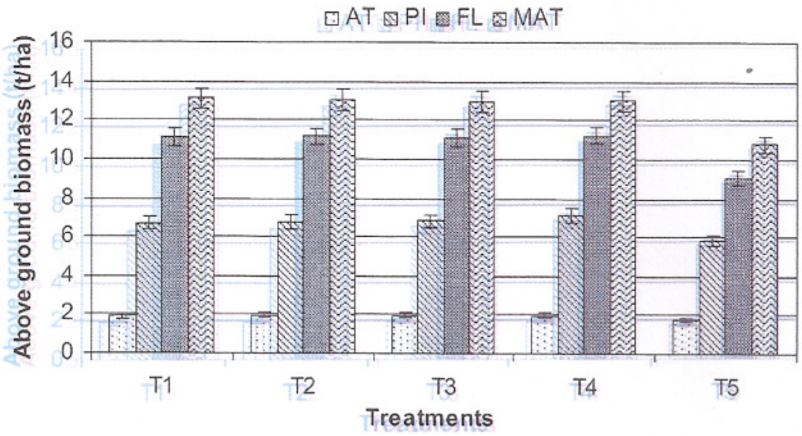

Figure 1. Observed maximum aboveground dry biomass with varying sources of nutrients. AT, active tillering; PI, panicle weight; FL, flowering; MAT, maturity; T_1, *Sesbania* + inorganic fertilizer; T_2, farmyard manure + inorganic fertilizer; T_3, pressmud + inorganic fertilizer; T_4, inorganic only; T_5, farmers' practice.

significantly different from treatments T_4 and T_5 (Figure 3) at the 0.05% probability level. Higher intercepted radiation by the crop was recorded under treatment T_1, which was attributed to higher aboveground biomass production under that treatment.

The grain yield of rice was also significantly influenced by the application of fertilizer (NPK) in conjunction with different sources of organic matter (FYM/press mud/green manures) applied to rice (Table 1). Pooled data from the three study years revealed that the highest yield (5380 kg ha^{-1}) of rice (cv. Gayatri) was obtained when 25% N fertilizer was supplied through green manures (*Sesbania rostrata*). The second highest yield (5250 kg ha^{-1}) was obtained with 75% N through inorganic fertilizer + 25% through pressmud, followed by the combination of 75% N through

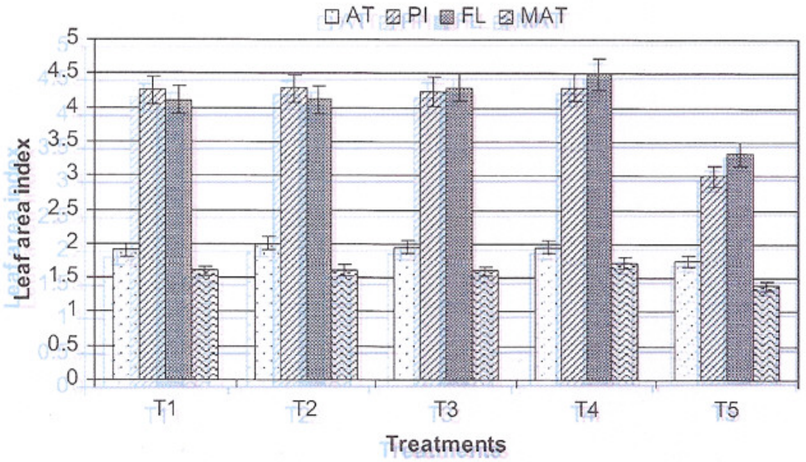

Figure 2. Observed leaf area index with varying sources of nutrients (pooled data). AT, active tillering; PI, panicle weight; FL, flowering; MAT, maturity; T_1, *Sesbania* + inorganic fertilizer; T_2, farmyard manure + inorganic fertilizer; T_3, pressmud + inorganic fertilizer; T_4, inorganic only; T_5, farmers' practice.

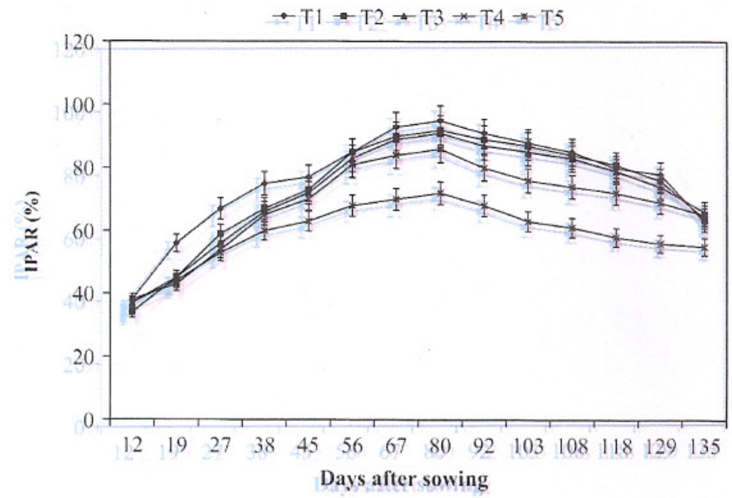

Figure 3. Intercepted photosynthetically active radiation (IPAR) by rice with different sources of plant nutrients. T_1, *Sesbania* + inorganic fertilizer; T_2, farmyard manure + inorganic fertilizer; T_3, pressmud + inorganic fertilizer; T_4, inorganic only; T_5, farmers' practice.

inorganic + 25% by FYM. However, the differences in grain yield in treatments T_1, T_2 and T_3 are not statistically significant at the 0.05 probability level. The grain yield decreased by 18.7% when only inorganic fertilizer was applied (T_4) compared with treatment T_1. Whereas, with farmers' management practices (T_5), only 2990 kg ha^{-1} rice was obtained, which was 46% lower than that obtaind with treatment T_1. The grain yield of rice was significantly reduced in treatments T_4 and T_5 compared with T_1–$T-{}^{3}$. Working on the impact of integrated nutrient management on rice in the region, similar results were obtained by Puste et al. (1999) and Reddy and Surekha (2000).

The highest grain yield was obtained when 25% N fertilizer was applied through green manure, *Sesbania* which might be due to the availability of more nutrients under that treatment. Green manuring might reduce the loss of mineral N by leaching and decrease ammonia volatilization losses and, as a result, fertilizer use efficiency was greater. The study revealed that although nutrient deficiencies could be met largely through chemical fertilizers, desirable soil physico-chemical properties such as water-holding capacity, congenial conditions for microbial activity and efficient use of applied fertilizers might be maintained by the addition of organic manures. As a result, rice productivity was greater under integrated nutrient management

Economics

Our study revealed that the highest total rice equivalent yield of 7095 kg ha^{-1} was obtained with the rice–pea sequence, when rice was grown with 75% N through inorganic fertilizer and 25% through green manures, *Sesbania* (Table 1). After growing second crops, the highest net return (Rs. 21,380 ha^{-1}) was also obtained from a rice–pea cropping system under treatment T_1. The second highest net return (Rs. 20792 ha^{-1}) was obtained in treatment T_3 with the same crop combination (rice–pea). Under treatment T_4 (inorganic fertilizer only) net returns of Rs. 16,916 ha^{-1}, Rs. 16,232 ha^{-1} and Rs. 16,536 ha^{-1} were obtained from rice–pea, rice–greengram and rice–blackgram, respectively. Under the farmers' management practices (rice–fallow), only Rs. 8764 ha^{-1}, Rs. 8232 ha^{-1} and Rs. 7548 ha^{-1} net profits were obtained in these three respective cropping systems, which were significantly lower than from all the other treatments at the 0.05 probability level.

Residual effects

After harvesting of rice with residual soil fertility, three pulses (pea, blackgram and greengram) were sown consecutively for three years during the *rabi*/dry (winter season) on the same land to explore the possibilities of growing these crops after rice with residual soil fertility and soil moisture. The effects of combined sources nutrients of rice to the yield of succeeding crops are presented in Table 1. All three crops achieved the highest yield (490, 463, 438 kg ha^{-1}) when the preceding rice crop was cultivated with 75% N through inorganic fertilizer along with 25% N through *Sesbania* (T_1). The results of this treatment were almost statistically on a par with treatments T_2 (75% N through inorganic fertilizer + FYM) and T_3 (75% N through inorganic fertilizer + press mud), but were significantly different from treatments T_4 (full inorganic fertilizer) and T_5 (farmers' practices). The yield increment in treatment T_1 over T_5 was 108, 134 and 194% from pea, greengram and blackgram,

Table 1. Effect of different sources of nutrients on the grain yield of *kharif* rice and subsequent winter crops in sequence (pooled data of 2000–2001 to 2002–2003).

	Grain yield (kg ha^{-1})					
		Winter crops				
Fertilizer + organic matter treatment on rice	Kharif rice	Pea	Greengram	Blackgram	Rice equivalent yield from the system (kg ha^{-1})	Net return from the system (Rs. ha^{-1})*
25% N through *Sesbania* (T_1)	5380 a	490	–	–	7095	21380
	5380 a	–	463	–	7001	21004
	5380 a	–	–	438	7023	21092
25% N through farmyard manure (T_2)	5080 a	480	–	–	6760	20040
	5080 a	–	428	–	6578	19312
	5080 a	–	–	405	6599	19396
25% N through press mud (T_3)	5250 a	485	–	–	6948	20792
	5250 a	–	433	–	6766	20064
	5250 a	–	–	395	6731	19924
100% inorganic (T_4)	4530 b	414	–	–	5979	16916
	4530 b	–	365	–	5808	16232
	4530 b	–	–	361	5884	16536
Farmers' practice (T_5)	2990 c	236	–	–	3816	8764
	2990 c	–	198	–	3683	8232
	2990 c	–	–	149	3512	7548

Note: *Net return includes value of straw yield of rice. Grain yield of kharif rice: LSD (0.05): 336.82. Means within a column with same letter are not significantly different as per the Duncan's Multiple Range Test for kharif rice yield.

Table 2. Water use efficiency of pulses during post-rainy season with residual soil fertility and moisture.

Treatments (nutrient sources)	Crop yield (kg ha^{-1})			Water use (mm)			Water use efficiency (kg ha^{-1} mm^{-1})		
	Pea	Greengram	Blackgram	Pea	Greengram	Blackgram	Pea	Greengram	Blackgram
25% N through *Sesbania*	490 a	463 a	438 a	315	310	305	1.56	1.49	1.44
25% N through farmyard manure	480 a	428 b	405 a	305	305	298	1.57	1.40	1.36
25% N through pressmud	485 a	433 b	395 b	307	310	315	1.58	1.40	1.25
100% inorganic	414 b	365 c	361 b	315	310	320	1.31	1.18	1.13
Farmers' practice	236 c	198 d	149 c	298	295	305	0.79	0.67	0.49

Note: Nutrient sources: SEM (±): 8.71; LSD (0.05): 28.48. Crops: SEM (±): 4.10; LSD (0.05): 12.14. Nutrient sources × Crops: LSD (0.05): 27.16. Crop yield means within a column with the same letter are not significantly different as per the Duncan's Multiple Range Test.

Table 3. Effects of different sources of nutrients on soil physical properties (0–0.30 m depth).

	2000 (before experiments)	2004 (end of experiments)					
Physical parameters	Farmers' practice	+ 25% N through *Sesbania*	25% N through farmyard manure	25% N through pressmud	Sole inorganic	Control, Farmer's practice (T_5)	LSD (0.05)
Soil porosity (%)	32.1 b	38.2 a	35.3 a	37.5 a	32.1 b	31.3 b	2.06
Available water capacity (m^3 m^{-3})	0.143 c	0.161 b	0.158 b	0.175 a	0.152 bc	0.141 c	0.013
Hydraulic conductivity (cm h^{-1})	1.26 b	1.58 a	1.55 a	1.53 a	1.29 b	1.25 b	0.080
Bulk density (Mg m^{-3})	1.57 a	1.52 b	1.53 b	1.52 b	1.59 a	1.58 a	0.0297
pH	6.7	6.6	6.7	6.4	6.5	6.7	NS
Electrical conductivity (dS m^{-1})	0.12	0.12	0.11		0.11	0.11	NS
Penetration resistance (MPa)	3.4 a	3.1 b	3.0 b		3.4 a	3.5 a	0.157
Organic carbon (%)	0.69 bc	0.85 a	0.82 a	0.79 ab	0.66 c	0.68 bc	0.117

Note: Means with same letter within the row are not significantly different as per the Duncan's Multiple Range Test for kharif rice yield.

respectively. Water use efficiency (WUE) was not significantly different among the integrated nutrient treatments (T_1, T_2, T_3), but 39.7–50.0, 43.2–55.0 and 56.6–66.0% lower WUE was recorded in treatment T_5 compared with treatments T_1, T_2 and T_3, respectively (Table 2). The highest WUE (1.56–1.58 kg ha^{-1} mm^{-1}) was achieved by pea crop under integrated nutrient management practices, and was significantly different from that achieved under treatments T_4 and T_5.

The study revealed that production of three pulses, viz., pea, blackgram, and greengram was statistically on a par when these were grown in plots where 25% of N was supplied by organic nutrients (green manure/FYM/press mud) to the first crop (rice). This might be due to the enhancement of fertilizer use efficiency when inorganic fertilizers were applied along with organic nutrients. In plot with organic nutrients added, water-holding capacity was increased (Table 3) and as a result, greater WUE might have been achieved when second crops were grown with integrated nutrient sources (inorganic fertilizer + *Sesbania*/pressmud/FYM).

Soil properties

The results with respect to changes in soil chemical properties after 3 years of experimentation with a rice–pulse cropping system revealed that relatively more soil organic carbon was found when nitrogen was applied in the form of urea along with *Sesbania*, followed by urea + FYM (Table 3). The inorganic and press mud combination of plant nutrients showed almost similar values to organic carbon and available N and P. Among the treatments studied, *Sesbania* + inorganic sources of nutrients (T_1) was found to be the best in improving physical and chemical properties of soil, followed by T_2 (inorganic fertilizer + FYM). Significant differences in organic carbon were not observed among integrated nutrient management treatments, but significantly higher organic carbon was observed compared with that of control or initial values after three years of experimentation. Inclusion of legumes in rice–fallow during the post-rainy season with carry-over residual soil moisture offers an excellent opportunity not only to supplement the N requirement of the succeeding rice crop, but also to improve soil structure that has been destroyed by puddling in rice and application of fertilizer N. Furthermore, the inclusion of low water requiring legumes like blackgram, greengram, pea in rotation with rice contributes to soil fertility by fixing atmospheric nitrogen in the rhizosphere.

Integrated nutrient management along with the introduction of legumes during the post-rainy season improved soil physical conditions also (Table 3). Soil porosity was enhanced from 31.3% in 2000 to 35.3–38.2% in 2004 (after 3 years of experimentation) under integrated nutrient management treatments. Hydraulic conductivity and available water capacity were enhanced by 23–26% and 29–31%, respectively, in the different integrated nutrient management treatments compared with controls.

Conclusion

The study revealed that, during the rainy season, 30–35% higher rice grain yield was obtained when combined sources of both inorganic and organic nutrients were applied compared with inorganic fertilizer alone, and the highest rice equivalent yield of 7095 kg ha^{-1} was obtained under the same treatment with a rice–pea cropping system. The findings of this investigation revealed that green manure *Sesbania* *rostrata* might be a better substitute for inorganic fertilizer. In addition to enhancing rice productivity, integrated nutrient management could improve soil physical and chemical properties.

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