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Research Paper

Evaluation of balanced nutrient application for improving productivity and nutrient-use efficiency of rice (*Oryza sativa*)–green gram (*Vigna radiata*) cropping system in Coastal ecosystem

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ABSTRACT

An on-farm experiment involving 96 farmers (24 farmers/year) in farmers' participatory mode was conducted during 2011–12 to 2014–15 in Mandirbazar and Kakdwip blocks of South 24 Parganas district, West Bengal to study the response of rice (*Oryza sativa* L.)–green gram [*Vigna radiata* (L.) Wilczek] cropping system to balanced nutrition. Both the crops of the experiment were treated with 7 nutrient combinations, viz. control, recommended N alone (80 kg N to rice and 20 kg to green gram), N with P (40 kg P_2O_5/ha), N with K (40 kg K_2O/ha) to both the crop, N with P+K, N with P+K+Zn (25 kg $ZnSO_4$) (Zn only to rice) and farmers' practice which were replicated at 24 fields in 6 villages of the blocks. Application of 80 kg N, 40 kg P_2O_5 and 40 kg K_2O along with 25 kg $ZnSO_4$/ha to rice alone recorded significantly higher grain (4.51 t/ha) as well as straw (6.48 t/ha) yield of rice, while 20 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha recorded significantly higher seed (0.92 t/ha) yield in the succeeding green gram. The maximum system rice equivalent yield (8.81 t/ha) and unit time system productivity (24 kg/ha/day) were also observed under balanced application of nutrients. Higher partial factor productivity (PFP) for N and K was recorded under farmers' practice and the same for P was higher under application of N with P+K+Zn. Significantly higher net returns (₹46,994/ha) with cost of cultivation of ₹62,710/ha, B:C ratio (1.76) and sustainable yield index (0.83) were recorded with application of N with P+K and Zn to rice and N+P+K alone to greeng ram in the system. Agronomic efficiency (AE) of applied nutrients were observed to be in the order of N<NP<NK<NPK< NPKZn for rice and N<NK<NP<NPK<NPKZn for green gram.

Key words **:** Balanced nutrition, Economics, Nutrient-use efficiency, Nutrient uptake, Rice–green gram system, Sustainable yield index

The intensified crop management involving improved germplasm, greater use of fertilizers and irrigation has increased the yield of cereal-based cropping systems during the last 30 years. India consumed 16.6 Tg N, 8.0 Tg P_2O_5 and 3.5 Tg K_2O in 2010 and occupied second position following China in N and P consumption. Regarding K and combined N + P_2O_5 + K_2O consumption, the country occupied the fourth and second place, respectively in the world. During the period from 1950-51 to 2007-08, the cereal production in the country increased by 5 times, whereas the fertilizers consumption increased by 322 times, indicating a very low fertilizer use efficiency (Prasad, 2009). The fertilizer response in irrigated areas of the country had declined almost 3 times from 13.4 kg grain/kg NPK in 1970 to 3.7 kg grain/kg NPK in 2005. This decline affects the economy of food production system in the country. A decrease in partial factor productivity of nitrogenous fertilizer is the most commonly observed effect of intensive cereal-based cropping systems (Hobbs and Morris, 1996). Reduced soil N supply results in declining factor productivity of chemical nitrogen, because soil N is natural substitute for chemical nitrogen. In post green revolution era multiple-nutrient deficiency including micronutrients is one of the important problems making system unsustainable (Jat *et al.,* 2016). Moreover, deficiency of Zn is very frequent in rice-based intensive system with no or little application of Zn fertilizer (Saha *et al.,* 2015).

Coastal flood plains of West Bengal spread over an area of 10,158.2 km^2 and represents lowland agro-ecosystem

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with heavy textured saline soils. Farmers of this region grow high yielding varieties of rice during wet season followed by green gram, grasspea and some other low water requiring crops (Ray *et al.,* 2016). Out of these systems rice–green gram is the dominant cropping system with 10,253 ha area and it largely affects the livelihood of the rural people. Imbalanced application of nutrients is one of the most important reasons for low productivity in rice–green gram system. Farmers generally apply 50–40–0 kg N–P_2O_5–K_2O/ha in rice and 15–30–0 kg N–P_2O_5–K_2O/ha in green gram from urea and diammonium phosphate (DAP). The whole amount of fertilizers is applied as basal. However, balanced nutrition increases the plant ability to absorb requisite amount of desired nutrients and thus, improve crop productivity and input-use efficiency (Panwar *et al*., 2018). Recovery of applied nitrogen or use-efficiency also proved to be higher by way of combining recommended quantity of P and K with nitrogen application as compared to application of N alone in different cropping systems (Ravisankar *et al*., 2014). With this backdrop of information, an experiment was carried out in farmers' field to assess the yield improvement, nutrient uptake, sustainability, factor productivity and agronomic efficiency of applied nutrients along with economics of balanced fertilization in rice–green gram cropping system for 4 consecutive years.

MATERIALS AND METHODS

An on-farm experiment on rice–green gram system was conducted during 2011–12 to 2014–15 in South 24 Parganas district situated in Coastal Saline Zone of West Bengal. The mean values of physical and chemical characteristics of soils across the sites at the initiation of experiment indicated that, soil was silty clay loam with *p*H 5.45, EC 0.59 dS/m, medium in organic carbon (0.72%), low in available N (140.50 kg/ha), high in available P and (48.10 kg/ha), K (281.5 kg/ha) and low in available Zn (0.59 ppm). The average minimum and maximum temperature that prevails in this area are 22°C and 34°C with average annual rainfall of 1,950 mm having 87 rainy days and humidity level of 85% and is prone to tidal wave and cyclones.

Seven treatments, viz. control, recommended N, N+P, N+K, N+P+K for both the crops, N+P+K+Zn to rice and N+P+K without Zn to green gram and farmers' practice were evaluated in rice and green gram cropping system grown during rainy (*kharif*) and summer seasons, respectively. Twelve farmers were selected from each of the 2 blocks thus totaling 24 farmers and all the 7 treatments were assigned to each of the farmers' field in a plot area of 50 m^2 for each treatment in a compact block of 350 m^2 area. Rice variety 'Ranjit' and for green gram 'local selection' (recommended for the location) were used in the experiment. The recommended dose of N–P_2O_5–K_2O–$ZnSO_4$ applied for rice was 80–40–40–25 kg/ha respectively, while for green gram it was 20–40–40 kg N–P_2O_5–K_2O/ha, respectively. In farmers' practice different amount of fertilizers were applied by the farmers, however, it was observed that on an average 52±19-56±35–24±21 kg/ha N–P_2O_5–K_2O and 18±5–34±11–10±12 kg/ha N–P_2O_5–K_2O were applied in rice and green gram, respectively. Both the crops were raised with recommended package of practices. In case of rice, both grain and straw yield were considered as economic yield, whereas, only seed yield of green gram was taken into consideration and the biomass was ploughed down after plucking the pods. The green gram yield was converted into rice-equivalent yield (REY) based on prevailing market price in the respective years. Unit time production efficiency in terms of kg/ha/day was calculated by dividing the total REY of rice–green gram system with 365 days and sustainable index of each treatment was calculated as described by Devsenapathy *et al.,* 2008. Nutrient-use efficiency (NUE) was expressed in terms of partial factor productivity (PFP) and agronomic efficiency (AE), which was calculated as per the methodology described by Cassman *et al*. (1996) and FAO (1989) respectively, for such balanced nutrition experiments. Sustainable yield index (SYI), was calculated as SYI= (Y_{mean}-SD)/Y_{max} ; where, Y_{mean}= average yield of a treatment, SD= standard deviation of that treatment and Y_{max}= maximum yield of that treatment. Plant samples of both the crops were analyzed for N, P and K uptake. Statistical analysis of the recorded data was done using SPSS software, IBM Inc. 2009 and critical difference (CD) was computed at 5% level of probability.

RESULTS AND DISCUSSION

Productivity of rice and green gram

Application of recommended dose of NPK along with zinc (Zn) resulted in significantly higher grain (4.51 t/ha) and straw (6.48 t/ha) yield of rice and seed yield (0.92 t/ha) of green gram (Table 1). The increase in grain yield of rice due to application of recommended doses of NPK along with Zn was 65, 29, 16, 12, 3.4 and 37% higher over the control, N, NP, NK, NPK and farmers' practice, respectively. In succeeding green gram, 61, 42, 18, 21, 5 and 43% higher seed yield was registered over control, N, NP, NK, NPK and farmers' practice, respectively where the crop was applied with recommended NPK and utilized the residual influence of $ZnSO_4$ applied to the preceding rice crop. Rice-equivalent yield (REY) and system productivity of rice–green gram system recorded significantly higher values (8.81 t/ha and 24.13 kg/ha/day, respectively), with application of NPK along with Zn in comparison with other applications. Significant improvement in grain/seed yield of rice and green gram might be attributed to accomplishment of better growth and development of crops due to recommended and balanced application of NPK nutrients. Phosphorus promoted better root development that led to absorption of adequate nitrogen while potassiums involved in better N metabolism. Owing to low Zn of experimental soils Zn application helped both the crops to record higher yields over application of NPK alone. The results are in agreement with Singh *et al.* (2017).

Partial factor productivity (PFP)

The PFP of applied N in rice ranged between 41.82–62.86 kg grain/kg of N, and significantly higher value was obtained under farmers' practice followed by NPK+Zn, NPK, NK, NP and N alone (Table 2). However, in green gram, the maximum PFPn was recorded under NPK+Zn (45.92 kg grain/kg of applied N), followed by NPK, NP, NK, farmers' practice (FP) and N alone, though the effect of this treatment was significantly at par with the effects of NPK, NK and NP. This increase in efficiency of N was by way of combining recommended quantity of P, K and Zn with nitrogen. Similarly, the recovery of P and K was higher when applied with N or P/K and Zn in both the crops. The maximum PFP_p was noticed under NPK+Zn (112.7 and 22.96 kg grain/kg of applied P in rice and green gram, respectively) followed by NPK (110.5 and 22.07 kg grain/kg of applied P in rice and green gram, respectively). The PFP_k was higher in FP (136.2 and 22.96 kg grain/kg of applied K in rice and green gram, respectively) followed by NPK+Zn (112.7 and 22.96 kg grain/kg of applied nutrient in rice and green gram, respectively). Farmers in the coastal area of West Bengal, in general, have a tendency to apply moderate amount of N (52 and 18 kg/ha in rice and green gram, respectively), slightly higher amount of P (56 and 34 kg/ha in rice and green gram, respectively) and very less amount of K (24 and 10 kg/ha in rice and green gram, respectively) and avoid application of Zn. It was justified from the higher values of PFP for N and K and lower values of PFP for P for both rice and green gram crops though the quantity of grain/seed yields obtained from this treatment was comparatively lower in respect of NPK + Zn treatment. Application of NPK + Zn registered higher value of PFP for P in both the crops. Balanced dose of nutrients along with Zn might have helped in better recovery of P from native soil as well as from the applied fertilizer. Haerdter and Fairhurst (2003) reported that the recovery of N from fertilizers increased from 16% at conventional NP application to 76% at balanced NPK fertilization.

Table 1. Grain/seed, straw and rice equivalent yield (REY) as influenced by balanced nutrient application (pooled data of 4 years)

Treatment	Rice grain yield (t/ha)	Rice straw yield (t/ha)	Green gram seed yield (t/ha)	REY (t/ha)	System productivity (kg/ha/day)
Control	2.74	4.39	0.57	5.39	14.76
N	3.49	5.05	0.65	6.55	17.95
NP	3.90	5.61	0.78	7.54	20.66
NK	4.02	5.80	0.76	7.56	20.72
NPK	4.36	6.29	0.88	8.48	23.23
NPK + Zn	4.51	6.48	0.92	8.81	24.13
Farmers' practice	3.27	4.67	0.64	6.27	17.17
SEm±	0.16	0.23	0.05	0.26	0.72
CD (P=0.05)	0.44	0.63	0.14	0.72	1.99

Table 2. Partial factor productivity (PFP) of N, P and K (kg grain/kg of applied + native nutrient) for rice and green gram as influenced by nutrient application

With single/ combination	PFP_N Rice	PFP_N Green gram	PFP_P Rice	PFP_P Green gram	PFP_K Rice	PFP_K Green gram
N/P/K	41.82	33.17	10.16	3.09	13.20	2.51
NP	49.38	39.35	98.76	19.67	–	–
NK	51.01	38.20	–	–	102.0	19.10
NPK	54.53	43.99	110.5	22.07	110.5	22.07
NPK + Zn	56.37	45.92	112.7	22.96	112.7	22.96
Farmer's practice	62.86	35.58	58.37	18.35	136.2	64.04
SEm±	2.06	2.86	3.19	1.36	3.94	1.96
CD (P=0.05)	5.73	7.95	8.87	3.78	10.96	5.45

Agronomic efficiency (AE)

The AE of applied N (AE_n) in rice ranged between 9.47–22.16 kg grain/kg of applied N, whereas in green gram it ranged between 4.11–17.25 kg grain/kg of applied N (Table 3). An increased propensity of agronomic efficiency of N was found with balanced application of nutrients (NPK) and the value was further enhanced when Zn was added. The values were found to be in the order N<FP<NP<NK<NPK<NPKZn for rice and FP<N< NK< NP<NPK<NPKZn for green gram. Significantly higher agronomic efficiency of P (AE_p) in rice and green gram was observed when P was applied with N, with NK and with NKZn than P alone. The value of AE_p ranged between 8.52–44.32 kg grain/kg of applied P and 2.18–8.63 kg grain/kg of applied P in rice and green gram, respectively. Similar trend of AE of K (AE_k) was noticed in rice and green gram. The highest value was noticed when K was applied with NP and Zn (44.32 and 8.63 kg grain/kg of applied K in rice and green gram respectively) followed by with NP, N, FP and K alone. However, in green gram, the AE_k was found at par with NPK + Zn and NP, but differed significantly from the other treatments. Balanced application ensures higher responses of nutrients in rice than green gram, which is mainly due to higher and efficient utilization of nutrients by cereal than legume (Ravisankar *et al.,* 2014). Balanced application of nutrients has helped in better recovery of N, P and K from native soil as well as from the applied fertilizers, as is evident from AE analysis of nutrients in rice–green gram system, which can be attributed to positive interaction effect of these nutrients in the growth and development of plants. Singh *et al.* (2017) also noticed a similar trend, where they observed on an average, AEn, AEp and AEk can be increased to the tune of 90.3%, 90.6% and 89.6% over the farmer practices by balanced application of NPK along with deficient micronutrients in the cereal crop-based systems.

Nutrient uptake

NPK uptake by rice (Table 4) was the highest when recommended rate of NPK was applied along with Zn. Likewise in green gram, an application of NPK coupled with Zn recorded higher uptake of N, P and K than the other treatments. In case of system nutrient uptake, the uppermost value was found under NPK+Zn. The higher yield and dry matter production in the treatment of NPK+Zn attributed to the higher nutrient uptake for both the crops in the system and also had the direct effect on the system nutrient uptake. There are two major factors which contribute to the nutrient-uptake by any crop namely, concentration of nutrient in the tissue and the potential dry-matter production. Hiremath *et al.* (2016) in chick pea–

Table 3. Agronomic efficiency (AE) of N, P and K (kg grain increased/kg applied nutrient) for rice and green gram as influenced by nutrient application

With single/ combination	AE_N Rice	AE_N Green gram	AE_P Rice	AE_P Green gram	AE_K Rice	AE_K Green gram
N/P/K	9.47	4.45	8.52	2.97	11.56	2.39
NP	14.55	10.62	29.09	5.31	–	–
NK	16.07	9.48	–	–	32.13	5.68
NPK	20.33	15.41	40.65	7.71	40.65	9.23
NPK + Zn	22.16	17.25	44.32	8.63	44.32	8.63
Farmer's practice	10.24	4.11	9.51	2.18	22.19	7.41
SEm±	1.67	2.43	2.66	1.24	3.58	2.53
CD (P=0.05)	4.64	6.76	7.40	3.45	9.96	7.04

Table 4. Nutrient uptake as influenced by different nutrient combinations (pooled over 4 years)

Treatment	Rice (kg/ha)			Green gram (kg/ha)		
	N	P	K	N	P	K
Control	77.9	9.9	69.1	15.3	5.0	19.5
N	91.7	11.5	77.0	16.8	5.4	21.8
NP	100.5	13.4	83.9	19.6	6.4	23.9
NK	98.3	12.5	92.8	19.2	6.1	25.0
NPK	105.5	16.2	99.6	22.2	7.4	27.5
NPK + Zn	107.8	16.5	99.0	23.1	7.3	28.6
Farmer's practice	70.4	8.9	63.3	15.9	5.3	20.8
SEm±	4.87	0.53	3.80	1.10	0.42	1.25
CD (P=0.05)	13.54	1.47	10.56	3.06	1.17	3.48

Table 5. Economic analysis and sustainable yield index (SYI) of rice–green gram system as influenced by nutrient combinations (pooled data of 4 years)

Treatment	Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio	Marginal returns (%)	SYI
Control	49.30	18.44	1.37	–	0.69
N	53.38	28.80	1.54	56.18	0.74
NP	58.39	35.86	1.62	94.47	0.78
NK	56.49	38.16	1.68	106.94	0.78
NPK	61.21	44.52	1.74	141.43	0.79
NPK + $ZnSO_4$	62.71	46.99	1.76	154.83	0.79
Farmers' practice	46.62	31.57	1.35	71.20	0.74
SEm±	0.69	3.26	0.06	–	0.012
CD (P=0.05)	1.92	9.06	0.17	–	0.030

maize and in maize–wheat also found the similar results.

Economic analysis and sustainability

Application of 80 kg N, 40 kg P_2O_5, 40 kg K_2O with $ZnSO_4$ @ 25 kg/ha in rice and 20 kg N, 40 kg P_2O_5, 40 kg K_2O in green gram resulted in significantly higher cost of cultivation (₹62,710/ha), net returns (₹46,994/ha) and benefit: cost ratio (1.76) of the rice–green gram system. However, the FP recorded significantly lower system cost of cultivation (₹46,620/ha) and benefit: cost ratio (1.35). The lowest value of system net returns (₹18,440/ha) was found under control. Marginal return over the control was found highest in NPK+Zn treatment (154%) followed by NPK (141%), NK (106%), NP (94%), FP (71%) and N (56%) (Table 5). Though the recommended NPK along with Zn recorded the highest cost of cultivation due to combination of more nutrients at highest levels, owing to the higher yields for both the crops, the marginal gain was higher than other treatments. These findings are in line with those of Sharma *et al.* (2011). Singh *et al.* (2017) also observed maximum net returns under the treatment receiving recommended dose of NPK+S in rice–wheat cropping system. Further in terms of sustainable yield index, application of 80 kg N, 40 kg P_2O_5, 40 kg K_2O, 25 kg $ZnSO_4$ to rice and 20 kg N, 40 kg P_2O_5, 40 kg K_2O to succeeding green gram excelled over all other combinations owing to consistent higher yield of rice and green gram over the locations and years.

Based on the findings of the investigation in farmers' participatory mode involving 96 farmers, it can be concluded that the application of 80 kg N, 40 kg P_2O_5, 40 kg K_2O, 25 kg $ZnSO_4$ to rice and 20kg N, 40 kg P_2O_5, 40 kg K_2O to succeeding green gram would be highly advantageous for realizing higher production, maintaining soil fertility at higher level and realizing higher economic return from the rice–green gram system under coastal ecosystem especially under coastal saline zones.

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