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Research Paper

Impact of integrated nutrient management on crop productivity and soil fertility under rice (*Oryza sativa*)–chickpea (*Cicer arietinum*) cropping system in Chhattisgarh plain agro-climatic zone

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ABSTRACT

A study was conducted during 2016–17 to 2018–19 at farmer's field under Farmer FIRST Project (FFP), at College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Waraseoni, Balaghat, Jabalpur, Madhya Pradesh, to assess the impact of integrated nutrient management on crop productivity, soil-nutrient balance and economics of rice (*Oryza sativa* L.)–chickpea (*Cicer arietinum* L.) cropping system. Application of 75% NPK + 5 t/ha farmyard manure (FYM) + biofertilizers [blue green algae (BGA)/*Rhizobium* and phosphate-solubilizing bacteria (PSB)] resulted in significantly higher grain yield of rice and chickpea (4,429 kg/ha and 1,538 kg/ha, respectively) over the Farmer Practice (3,644 kg/ha and 1,036 kg/ha respectively). The maximum nutrients uptake (N, P and K) by rice and chickpea crops were recorded in the treatment receiving 75% NPK + 5 t/ha FYM + biofertilizers. The conjunctive use of inorganic fertilizers along with organic manure and biofertilizers exhibited the highest availability of soil N, P, K and Zn at post-harvest of chickpea crop as compared to the other treatment combinations. Further, results showed that the highest cost of cultivation (₹58,200/ha) and net returns (₹96,832/ha) were obtained in 75% NPK + 5 t/ha FYM + biofertilizers treatment. The benefit: cost (B: C) ratio computed for rice–chickpea cropping system indicated that, the higher B: C ratio was found to be associated with higher production and better quality of the produce.

Key words: FFP, INM, Nutrient availability, Net return, Production efficiency, Vertisol

Rice (*Oryza sativa* L.)–chickpea (*Cicer arietinum* L.) is the prevalent cropping system in Chhattisgarh plain agro-climatic zone of Balaghat district. Chickpea is capable of enriching the soil for succeeding crops, and has suitability for inclusion in different cropping systems. However, rice is used as a premier foodgrain crop in Madhya Pradesh and India. As rice is a cereal and chickpea is a legume pulse crop, they together complement each other in the cropping system and help in maintaining and/or sustaining the soil health. Therefore, rice–chickpea cropping system is not only economically viable and eco-friendly for sustaining soil fertility but also for obtaining higher system productivity in long term. Thus, rice–chickpea cropping system emerged as an efficient cropping system of Madhya Pradesh and India.

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The availability of nutrients in the soil for plant utilization is affected not only by the inherent soil characteristics but also by the fertilizer use and practices followed in a cropping system. It has been observed that a major part of the applied nutrient gets fixed and only a small part of it becomes available to the crop plants at farmer's field (Thakur *et al.,* 2021). The organic matter like farmyard manure (FYM) being the storehouse of nutrients, combined application of organic and inorganic fertilizers can increase the yield, improve the fertility status of soil, improve the input-use efficiency by the crop, and can certainly cut down the expenditure on costly fertilizers (Thakur and Sawarkar, 2009). However, the microbial inoculants (biofertilizers) are required to promote adequate supply of nutrients to the host plants to ensure their proper growth and development, by regulating various physiological processes. Among the biofertilizers N_2 fixing biofertilizers, i.e. blue green algae (BGA) Cynobacteria, *Rhizobium* and phosphate-solubilizing bacteria (PSB), offer great promise to the crops, enabling the inoculated plants for more uptake of nutrients particularly nitrogen and phosphorus from the soil. Further, the integration of inorganic fertilizers, organic manures and biofertilizers will not only sustain the crop production but also is effective in improving soil health and enhancing the nutrient-use efficiency (Sharma *et al.,* 2015). Thus, the balance dose of inorganic fertilizers along with organic manure and biofertilizers offers a great scope for enhancing productivity of different cropping systems and for sustaining soil health. Therefore, different field demonstrations were undertaken to assess the impact of integrated nutrient management on crop productivity, profitability of rice–chickpea cropping system and sustainable soil health.

MATERIALS AND METHODS

The present study was conducted under the on going ICAR funded project on Farmer FIRST at College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Waraseoni (Balaghat), Jabalpur, Madhya Pradesh, India. Balaghat is one of the tribal districts of Madhya Pradesh (21º34’56'' N and 79º47’31'' E) and uniquely situated in Chhattisgarh plain agro-climatic zone. The study area possesses a semi-arid and sub-tropical climate, with a characteristic feature of dry summer and cold winter. The total annual rainfall varies from 1,400 to 1,500 mm, with the mean value of around 1,400 mm.

The field demonstrations were conducted during rainy (*kharif*) and winter (*rabi)* season of 2016–17, 2017–18 and 2018–19 in the adopted villages, viz. Lendejhari, Chillod and Koppe, under Farmer FIRST project. At the beginning of the experiment, soil samples were collected before application of treatments and analyzed for basic soil properties (Table 1).

The experiment was laid out in a randomized block design with 5 treatments, comprising different combinations of inorganic fertilizers, organic manures and biofertilizers, replicated 4 times. The details of the treatments are: T_1, Farmer practice (as control); T_2, 100% NPK; T_3, 100% NPK + Zn; T_4, 75% NPK+ 5 t/ha FYM ha; and T_5, 75% NPK + 5 t/ha FYM + biofertilizers [blue green algae (BGA), *Rhizobium* and phosphate-solubilizing bacteria (PSB)]. The demonstrations were conducted at college field and in adopted villages (Lendejhari, Chillod and Koppe) under FFP which were treated as replication for the present investigation.

The 100% optimal NPK doses based on soil-test values were 100 : 60 : 40 and 20 : 60 : 20 (N : P_2O_5 : K_2O) kg/ha for rice and chickpea respectively. The sources used for N, P and K were urea, single superphosphate and muriate of potash, respectively. In rice crop, 50% N, 100% P and 100% K were applied basal before last harrowing and rest 50% N was applied in 2 equal splits-first half at 21–25 days and rest at 51–55 days after transplanting (DAS). In chickpea crop, all the nutrients (NPK) were applied basal before the last harrowing. In addition to these applications, $ZnSO_4$ was applied @ 25 kg/ha only in rice crop to the treatment with Zn. The farmyard manure was applied @ 5 t/ha/year to rice crop only 10–15 days before transplanting. Different biofertilizers used in different crops, i.e. BGA in rice, *Rhizobium* in chickpea and PSB was applied @ 3–5 kg/ha in both the crops. In Farmer Practice treatments, application of only diammonium phosphate (DAP) fertilizer was done @ 125 kg/ha in both the crops just before transplanting and/ or sowing. Urea was applied only in rice crop only @ 250 kg/ha in 2 equal split doses–first at 21–25 days and rest at 51–55 days after transplanting.

Rice variety ‘JR 206’ was grown as rainfed in the first/ second week of July during the rainy season and harvested in 115–120 days which was followed by chickpea variety ‘JG 63’ which was sown in the first week of November as also rainfed situation during the winter season (*rabi*) and harvested in 100–105 days. Chemical herbicides, i.e. Bispyribac sodium @ 250 ml/ha for rice and Pendimethilin @ 1.25 L/ha for chickpea were used for weed control. Insects and diseases were kept under control by following suitable control measures. Rice and chickpea crops were harvested at maturity and yield data were recorded after threshing.

The soil samples (0–15 cm depth) were taken after harvesting of chickpea crop during 2018–19. The soil samples

Table 1. Effect of continuous cropping and fertilizer use on nutrient status of soil after harvesting of chickpea (2018–19)

Treatment	Soil *p*H	Organic carbon (g/kg)	Available nutrients (kg/ha)			Available Zn (mg/kg)
			N	P	K	
Farmer Practice	7.2	6.3	259.5	16.1	240.7	0.59
100% NPK	7.1	6.7	296.8	18.3	266.3	0.60
100% NPK +Z n	7.2	6.8	301.7	18.7	267.9	0.73
75% NPK + FYM	7.1	7.1	306.2	19.5	273.4	0.63
75% NPK + FYM + BF	7.0	7.2	309.8	20.4	274.1	0.64
CD (P=0.05)	NS	0.10	23.7	2.20	13.1	0.11
Initial value (2016–17)	7.0	6.6	262.0	17.0	250.0	0.61

BF, Biofertilizer

were analysed through standard laboratory procedures for different soil properties, viz. soil *p*H, organic carbon, available N, P, K and Zn.

The grain and straw of rice and chickpea were taken to determine nutritional (NPK) content. On the basis of nutrient content, the nutrient uptake was calculated in kg/ha in relation to dry-matter production (yield kg/ha).

To assess the resource-use efficiency of the system, in terms of production efficiency (%), was calculated by dividing standard output (yield) by actual output, and expressed in percentage form. The economics was calculated on the basis of prevailing market prices of different inputs and outputs.

The study was based on a randomized block design with 4 replications for each treatment. The data generated on soil analysis, yields and nutrient uptake were statistically analysed to draw inferences.

RESULTS AND DISCUSSION

Basic soil properties:

There were no significant a difference in soil reaction (*p*H) due to different treatments of fertilizers and manure (Table 1). The soil organic carbon content increased significantly from its initial value of 6.6 g/kg to attain a maximum value of 7.2 g/kg in the treatment comprising 75% NPK along with FYM and biofertilizers. This could be ascribed owing to the addition of organic material by annual use of 5 t/ha FYM during the period of experimentation. Further, increasing levels of fertilizer application helped in increasing the soil organic carbon content because of increased contribution from the biomass, as it was also observed that with increasing levels of fertilizer application, the crop yields was increased. The contribution from root stubble could also be expected to follow the same trend (Thakur *et al.,* 2011; Patel *et al.,* 2018).

Available nitrogen content ranged from 259.5 to 309.8 kg/ha (Table 1) and the highest value was noted with treatments where integration of inorganic fertilizer with organic manure and biofertilizers was done. Such an increase in available N might be owing to the mineralization of FYM and atmospheric nitrogen fixation by BGA and *Rhizobium* biofertilizers (Thakur *et al.,* 2009). The soil-available P (Table 1) was either maintained or significantly improved with the addition of different organic manure and PSB with inorganic fertilizers over the Farmer Practice (20.4 kg/ha). Organic manures, on decomposition, solubilize insoluble organic P fractions through release of various organic acids, thus resulting in a significant improvement in available P status of the soil (Sharma *et al.,* 2015). Similarly, the highest value of available K was recorded (274.1 kg/ha) under conjoint use of inorganic fertilizers with organic manure and biofertilizers treatment, while the lowest in Farmer Practice (240.7 kg/ha). Further, the available K content was depleted in Farmer Practice plot from its initial value (250 kg/ha). This may be due to continuous application of imbalanced nutrition (N or NP alone) in soil. Continuous omission of K in crop nutrition caused mining of its native pools that caused reduction in the crop yields (Pathariya *et al.,* 2022). The findings further revealed that, addition of zinc along with 100% NPK significantly raised the level of available Zn content (0.73 mg/kg) in the soil (Table 1). Sawarkar *et al.,* (2010) also reports a significant buildup of available Zn with the to application of zinc sulphate. Further, the inclusion of FYM also contributed significantly to the buildup of Zn content (0.64 mg/kg) in soil over the initial value (0.61 mg/kg). This could be attributed to direct contribution of FYM to nutrient pool or its beneficial effects either through complexation or mobilization of native Zn (Sharma *et al.,* 2015).

Crop Productivity:

The highest pooled average grain yields of rice (4,429 kg/ha) and chickpea (1,538 kg/ha) were obtained in treatment comprising 75% NPK with organic manure and biofertilizers (75% NPK + FYM + BF) and the lowest yield of rice (3,644 kg/ha) and chickpea (1,026 kg/ha) were recorded in control plot (Farmers Practice) (Table 2). The

Table 2. Response of different nutrients on yields and nutrient (NPK) uptake by rice–chickpea cropping system (pooled mean of 3 years)

Treatment	Pooled grain yield and nutrient (NPK) uptake by rice (kg/ha)				Pooled grain yield and nutrient (NPK) uptake by chickpea (kg/ha)			
	Yield	N	P	K	Yield	N	P	K
Farmer Practice	3,644	63.4	16.3	104.1	1,036	16.4	12.8	51.7
100% NPK	4,128	65.1	18.6	107.3	1,390	24.3	21.5	71.3
100% NPK + Zn	4,270	65.8	18.9	107.9	1,426	25.1	22.3	72.8
75% NPK + FYM	4,355	66.2	19.7	109.2	1,492	26.2	23.8	73.9
75% NPK + FYM + BF	4,429	68.3	20.5	110.1	1,538	27.4	24.5	75.6
CD (P=0.05)	218.0	2.16	1.52	4.06	186.0	1.89	2.01	2.57

BF, Biofertilizer

results of 3 cycles of experiment indicated that, the imbalance dose of nutrients (N and P only) reduced the yield by 11.7% and 26.2% for rice and chickpea, respectively, from 100% NPK. Continuous application of N and P only exhibited declining trend with time due to imbalanced use of nutrients (Thakur and Sawarkar, 2009; Gour *et al.,* 2015). These findings clearly indicated that the highest crop response in terms of yield was found with balanced fertilization. Balanced fertilization is the key to efficient fertilizer utilization for sustaining high yields. These findings indicated that, an integrated use of inorganic fertilizer, organic manure and biofertilizers treatment was superior to the optimal application of fertilizers (100% NPK). Thus, the balanced use of fertilizer either alone or in combination with organic manure is necessary for sustaining soil fertility and productivity of crops (Sharma *et al.,* 2015).

Nutrients (NPK) uptake by rice–chickpea cropping system:

The highest nutrients (NPK) uptake by rice and chickpea were observed in 75% NPK + FYM + biofertilizers treatments, while the lowest uptake in Farmer Practice (Table 2). The pooled data of 3 years revealed that, the integrated nutrient management (INM) treatments increased the nutrients uptake by rice and chickpea. The higher nutrient uptake with organic manure and biofertilizers treatment might be attributed due to solubilization of native nutrients, chelation of complex intermediate organic molecules produced during decomposition of added organic manures, their mobilization and accumulation of different nutrients in different plant parts (Sharma *et al.,* 2015; Dwivedi *et al.,* 2016).

Nutrient balance in rice–chickpea cropping system: The maximum available nitrogen status was observed in 100% NPK + FYM treatment (15.9 kg/ha/year) from its initial values (Table 3). In case of phosphorus balance, P was relatively immobile in soil as compared to N and K, especially in Vertisols and it was confined only to upper layer of profile. Appreciable increase in available P status in soil was recorded in all the treatments except Farmer Practice. The maximum negative balance of K in soil was recorded in Farmer Practice, as also reported by Sawarkar *et al.,* (2013).

Production Efficiency (PE):

Production efficiency of the rice–chickpea cropping system was the highest under the integrated nutrient management practice of 75% NPK + FYM + biofertilizers (98.4% and 69.9%) and the lowest in Farmer Practice (Singh *et al.,* 2021).

Economics of rice–chickpea cropping system

The results revealed that, the higher cost of cultivation of rice–chickpea cropping system under integrated nutrient

Table 3. Nutrient balance under rice–chickpea cropping system after harvesting of chickpea (2018–19)

Treatment	Available nutrient contents after harvest of chickpea (kg/ha)			Apparent nutrient changes as compared to their initial values (kg/ha)			Increase/decrease in nutrient content of soil/year (kg/ha/year)		
	N	P	K	N	P	K	N	P	K
Farmer Practice	259.5	16.1	240.7	–2.5	–0.9	–9.3	–0.8	–0.3	–3.1
100% NPK	296.8	18.3	266.3	34.8	1.3	16.3	11.6	0.4	5.4
100% NPK + Zn	301.7	18.7	267.9	39.7	1.7	17.9	13.2	0.6	6.0
75% NPK + FYM	306.2	19.5	273.4	44.2	2.5	23.4	14.7	0.8	7.8
75% NPK + FYM + BF	309.8	20.4	274.1	47.8	3.4	24.1	15.9	1.1	8.0
Initial value (1972)	262.0	17.0	250.0	–	–	–	–	–	–

Table 4. Effect of different treatments on production efficiency and economics of rice–chickpea cropping system (pooled mean of 3 years)

Treatment	Production efficiency (%)		Cost of cultivation (₹/ha)			Gross returns (₹/ha)			Net returns (₹/ha)			Benefit: cost ratio
	Rice	Chickpea	Rice	Chickpea	Total	Rice	Chickpea	Total	Rice	Chickpea	Total	
Farmer Practice	80.9	44.0	28,800	26,500	55,300	65,992	50,401	116,393	37,192	23,901	61,093	2.10
100% NPK	91.7	63.1	28,750	28,400	57,150	74,758	67,623	142,381	46,008	39,223	85,231	2.49
100% NPK + Zn	94.8	64.8	29,600	28,400	58,000	77,329	69,472	146,801	47,729	41,072	88,801	2.53
75% NPK + FYM	96.7	67.8	29,500	27,900	57,400	78,869	72,585	151,454	49,369	44,685	94,054	2.64
75% NPK + FYM + BF	98.4	69.9	30,100	28,100	58,200	80,209	74,823	155,032	50,109	46,723	96,832	2.66

BF, Biofertilizer

management practices (Table 4) was observed in 75% NPK + FYM + biofertilizers (₹58,200/ha), while, lower cost of cultivation in Farmer Practice (₹55,300/ha). The net returns were also found the highest under the nutrient management of 75% NPK + FYM + biofertilizers treatments (₹96,832/ha) and the least in Farmer Practice (₹61,093/ha). The benefit: cost ratio was significantly higher under the integrated nutrient management treatments, i.e. 2.66 in 75% NPK + FYM + biofertilizers than that of Farmer Practice (2.10). Thus, the rice–chickpea cropping system cultivation grown with integrated application of inorganic fertilizers with organic manure and biofertilizers was found productive and profitable. Our results confirm the findings of Sharma *et al.,* (2015) and Jat *et al.,* (2021).

It is concluded that the conjoint use of organic manure and biofertilizer along with 75% NPK not only sustains the higher yield of rice–chickpea cropping system, but also improves the soil health/fertility.

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