Indian Journal of Agronomy **68** (3): 253–259 (September 2023)

Research Paper

Effect of rice-establishment methods and nutrient management on productivity, profitability and soil health under rice (*Oryza sativa*)–groundnut (*Arachis hypogaea*) cropping system

T.K. SAMANT[1], L.M. GARNAYAK[2], R.K. PAIKARAY[2] AND P.J. MISHRA[2]

Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751 003

Received: October 2022; Revised accepted: July 2023

ABSTRACT

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2019–20 and 2020–21 at the Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, to study the effect of different rice-establishment methods and nutrient management on yield, economics and soil properties in rice (*Oryza sativa* L.)–groundnut (*Arachis hypogaea* L.) cropping system. The experiment was laid out in a split-plot design with 3 replications. Six treatment combinations, comprising of 2 rice-establishment methods, viz. direct-seeded rice (DSR) and transplanted rice (TPR) and 3 levels of nutrient-management practices, viz. inorganic-100% soil test-based fertilizers (STBF), organic-*dhaincha* [*Sesbania aculeata* (Wild.) Pers.] green manuring +1/3rd soil test-based nitrogen (STBN) through vermicompost @2 t/ha + 1/3rd STBN through neem oil-cake @ 0.87 t/ha and integrated nutrient management (INM), viz. green-manuring + 50% STBN (inorganic @ 50.0 kg N/ha) + 100% P_2O_5 + 100% K_2O, in rice during *kharif* were allotted to the main-plots. Three nutrient-management practices to groundnut during *rabi*, viz. 75% STBF, 100% STBF and 75% STBN (inorganic) + 25% STBN through FYM @ 1.63 t/ha + 0.2 lime requirement @ 0.38 t lime/ha + biofertilizers (*Rhizobium* + phosphate-solubilizing bacteria) + 100% P_2O_5 + 100% K_2O, were allotted to the sub-plots. Transplanting of rice (TPR) increased the yield parameters of rice, resulting in 3.3% higher grain yield (5.65 t/ha) than direct seeding of rice. The INM improved the yield parameters of rice, resulting in 13.3 and 15.2% increase in grain yield over sole inorganic and organic practice, respectively. Carryover effect of the DSR on succeeding groundnut crop improved the yield attributes and resulted in 15.8% higher pod yield (2.49 t/ha) than the groundnut crop grown after TPR. Residual effect of organic nutrient management in rice crop enhanced the yield parameters of succeeding groundnut, resulting in 4.2 and 16.5% higher pod yield than the groundnut grown after INM and inorganic practice in rice, respectively. The INM practice in groundnut increased its yield parameters, resulting in 11.4 and 18.1% higher pod yield over 100% and 75% STBF, respectively. The DSR enhanced the system yield (12.51 t REY/ha) of rice-groundnut cropping system by 6.8% over TPR. The INM practice in rice crop enhanced system yield by 12.6 and 4.2% over inorganic and organic practice, respectively. Similarly, INM to groundnut crop resulted in 7.4 and 11.2% higher system yield than 100% and 75% STBF, respectively. The DSR, INM practice in rice and INM practice in groundnut crop fetched higher gross returns (₹240.4 $\times 10^3$/ha, 245.5 $\times 10^3$/ha and 247.0 $\times 10^3$/ha), net returns (₹97.2 $\times 10^3$/ha, 108.9 $\times 10^3$/ha and 92.7 $\times 10^3$/ha), benefit: cost ratio (1.71, 1.80 and 1.62) and system profitability (₹207.9, 298.5 and 254.1/ha/day). Organic management under DSR and INM in groundnut improved the physico-chemical and biological properties of soil.

Key words: Cropping system, Groundnut, Microbial population, Profitability, Rice-equivalent yield, Soil health

Rice (*Oryza sativa* L.) and rice-based cropping systems are integral part of agriculture whose spread and extent is predominant across the countries. India occupies the world's largest area (44.5 million hectares) under rice and is the second highest producer (121.26 million tonnes), contributing 22% of global rice production. But its low productivity (2.75 t/ha) worries more than 60% of Indian population, who depends on rice for their food and nutritional security (Kundu *et al*., 2020). Inclusion of oilseeds and legumes changes the economics of the rice-based cropping systems, as these crops are receiving more attention for their limited production and higher prices (Deep *et al.*, 2018). Groundnut (*Arachis hypogaea* L.) is a unique and important legume oilseed crop in India, which is grown in 4.9 million hectares area with production of 10.14 million

[1]**Corresponding author's Email:** tksamant_2003@yahoo.co.in
[1]Scientist (Agronomy), Krishi Vigyan Kendra, Odisha University of Agriculture and Technology, Angul, Odisha 759132; [2]Professor (Agronomy), Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751003

tonnes and productivity of 1.78 t/ha as compared to the world average of 2.00 t/ha (DES, 2020). Rice-groundnut is an important cropping system in Odisha. Rice is predominant crop of Odisha, covering about 67% of the total cultivable area of the state in the rainy (*kharif*) season and groundnut is the major oilseed crop grown in 0.26 Mha, out of which winter (*rabi*) season groundnut accounts for about 69% area. Both the crops in the system are nutrient exhaustive and sensitive to changing climate. Deterioration of soil properties due to improper crop and nutrient management has threatened the productivity and sustainability of the system in the state (Patra *et al*., 2019).

Continuous rice monocropping and excessive dependence on chemical fertilizers degrade the soil quality, which can be partly solved by changing into rice–legume cropping system. It is pertinent to suggest suitable rice-based cropping system and nutrient management practices to get higher yield and income with maintaining the soil fertility. Use of high-analysis fertilizers debars the crop of availing the micronutrients and balanced fertilization. Organic manures and biofertilizers have carry-over effect on the succeeding crops in rice-based cropping systems. Organic and INM in rice besides maintaining soil quality is expected to have residual effect on succeeding crop thereby reducing its fertiliser need to a suboptimal level, i.e., 75% recommended dose of fertiliser (RDF). Efficient nutrient management through integration of all possible sources of nutrients can fulfill the phasic requirements of crops and increase crop productivity. Combination of organic and inorganic sources of nutrients improves the yield, nutrient-use efficiency and soil health (Biswas *et al*., 2023). Low productivity in groundnut is mainly due to use of imbalanced plant nutrients, and application of manures and fertilizers is reported to affect the availability of soil nutrients and soil physical properties of groundnut (Salma *et al*., 2018). However, conclusive evidences on balance nutrition of groundnut, particularly in rice–groundnut system, are still meagre and fragmentary in coverage. Method of stand establishment influences the performance of rice crop and has great impact on field preparation and establishment of succeeding *rabi* crops (Pandey *et al*., 2018). Being a labour-intensive and expensive operation, transplanted rice could be substituted by direct-seeded rice (DSR) for labour saving of 20% in terms of working hour (Mohapatra *et al*., 2022). The DSR improves the physical condition of soil and repeated puddling in transplanted rice, on the other hand, adversely affects it and the performance of following non-rice crop in the rotation (Tripathi *et al*., 2005). Hence keeping all the factors in view, a field experiment was conducted on rice–groundnut cropping system to find out the impact of different nutrient management and rice-establishment methods on yield, economics and soil properties.

MATERIALS AND METHODS

A field experiment was conducted, under irrigated condition, during rainy (*kharif*) and winter (*rabi*) seasons of 2019–20 and 2020–21 at Agronomy Main Research Farm of the Odisha University of Agriculture and Technology, Bhubaneswar (20°15' N, 85°52' E, 25.9 m above mean sea-level) under East and South Eastern Coastal Plain Agro-Climatic Zone of Odisha. The soil was loamy sand, having *p*H 5.28, medium in organic carbon (0.57%), available phosphorus (15.4 kg/ha) and available potassium (189.4 kg/ha) and low in available nitrogen (187.5 kg/ha) content. The experiment was laid out in split-plot design, replicated thrice. Six treatment combinations, comprising 2 establishment methods, viz. direct-seeded rice (DSR) and transplanted puddled rice (TPR), and 3 nutrient management practices, viz. inorganic–100% soil-test based fertilizers (STBF), organic–green manuring + 1/3rd STBN (soil-test based nitrogen) through vermicompost + 1/3rd STBN through neem oil cake and integrated nutrient management (INM), i.e. green manuring with *dhaincha* [*Sesbania aculeata* (Wild.) Pers.] + 50% STBN + 100% P_2O_5 + 100% K_2O to rice during *kharif* were allotted to the main-plots. Three nutrient-management practices, viz.75% STBF (inorganic), 100% STBF (inorganic) and INM [75% STBN + 25% STBN (FYM) + lime 0.2 lime requirement (LR) + biofertilizers, i.e., *Rhizobium* and phosphate-solubilizing bacteria (PSB) + 100% P_2O_5 + 100% K_2O to groundnut during *rabi* were allotted to the sub-plots at the same plot during both the years in rice–groundnut cropping system. Rice (cv. ‘Maudamani’) and groundnut (cv. ‘Devi’) were grown with standard agronomic management practices. As soil of experimental field was low in available nitrogen, medium in available phosphorus and potassium, the rice crop was fertilized as per STBF, i.e., 100-40-40 kg N-P_2O_5-K_2O/ha. The N, P and K were applied through urea (46% N), di-ammonium phosphate (18% N, 46% P_2O_5) and muriate of potash (60% K_2O), respectively, in inorganic nutrient-management practices in rice crop.

Under organic management in rice, *dhaincha* plants were incorporated into the soil at 42 days stage as green-manure with power tiller before transplanting and brown manuring was done manually in DSR. Vermicompost and neem oil-cake (NOC) were applied basal to supply, 1/3rd STBN, each based on their N equivalence. As per schedule, *dhaincha* green/brown manuring and 50% STBN were applied through urea with full P and K dose in INM practice in rice. Before application, all of them were analysed for their N content. The N content of vermicompost and neem oil-cake used were 1.62 and 3.85% during 2019–20 and 1.56 and 3.82% during 2020–21, respectively. Accordingly, their doses were decided to meet the soil test-based requirement. Vermicompost @ 2.05 t/ha and @ 2.13 t/ha, and neem oil-cake @ 0.865 t/ha and @ 0.872 t/ha, were applied, respectively, during 2019–20 and 2020–21 after layout of the experiment as per treatments.

Sowing of DSR and nursery were at same time and *dhaincha* in transplanted rice plot was sown 14 days earlier than DSR plot. In DSR, rice was sown with *dhaincha* and in TPR, rice was transplanted after incorporation of *dhaincha* at 42 days stage. After *dhaincha* incorporation, the land of individual plot was again puddled and levelled before transplanting. *Dhaincha* in DSR was brown manured by knocking down *dhaincha* with spraying of 2,4–D ethyl ester at same stage.

Soil test-based fertilizer dose of 25-40-40 kg N-P_2O_5-K_2O/ha in the form of urea, di-ammonium phosphate and muriate of potash was applied basal at the time of groundnut sowing in 75% and 100% STBF for inorganic treatment. The INM treatment in groundnut was designed to supply 75% STBN through inorganic source, i.e. urea and 25% STBN through FYM @1.63 t/ha with full P and K. The FYM was incubated with PSB @ 4 kg/100 kg of FYM before application. Kernels were inoculated with *Rhizobium* @ 20 g each/kg before sowing and 0.2 LR @ 0.38 t lime ($CaCO_3$)/ha were applied basal in lines at the time of sowing.

All the yield attributes and yield of both the crops were recorded at the end of each season and rice-equivalent yield was computed at the end of each cropping cycle as per standard procedures. Production efficiency and system profitability were calculated as per Gangwar *et al*., (2003).

Soil samples were collected at initial and end of cropping cycle from a depth of 0–15 cm from each treatment and bulk density, *p*H, organic carbon, available N, P and K contents were determined following the standard procedures. Population of soil micro-organisms (bacteria, actinomycetes and fungi) before the layout of experimentation and at the end of 2 years was estimated by serial dilution and plating technique. Economic analysis was done by calculating cost of cultivation, gross returns, net returns and benefit:cost ratio. The data were subjected to pooled analysis over 2 years as prescribed and following standard analysis of variance technique (ANOVA) of factorial randomized complete-block design for rice and split-plot design for groundnut and the system.

RESULTS AND DISCUSSION

Yield attributes and yield

Rice: The TPR gave higher yield attributes, i.e. panicles/m^2 (288.3), lengthier panicles (22.4 cm) with more grains/panicle (185.8) resulting in 3.3% yield improvement over DSR (Table 1) in spite of marginally lower test weight (24.37 g) and sterility percentage (15.24%), which might be owing to better microclimatic conditions and the improvement in soil physico-chemical properties for better water uptake as well as better availability and utilization of nutrients in properly spaced, puddle transplanted crop (Bastola, 2020).

The INM practice in rice, comprising green-manuring + 50% STBN + 100% P_2O_5 + 100% K_2O resulted in the maximum number of panicles/m^2 (321.0) being, on an average, 18.5 and 35.0% more than the inorganic and organic practice, respectively, but was at par with the inorganic practice in grains/panicle (190.2). The INM practice ensued in the highest grain yield (5.35 t/ha), which outyielded both the inorganic and the organic practices by 13.3 and 15.2%, respectively. Combined application of green manures and fertilizer N was proved to be more beneficial because of the improvement in soil physical conditions and soil microbial activity leading to increased availability and overall balanced nutrition (Ghosh *et al.,* 2021).

The crop-establishment methods resulted at par straw yield, though values were marginally higher (2.8%) in TPR than DSR. On an average, the INM practice provided the

Table 1. Effect of rice-establishment methods and nutrient management on yield attributes and yield of rice (pooled data of 2 years)

Treatment	Panicles/m^2	Panicle length (cm)	Grains/ panicle	Sterility (%)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Rice-establishment method								
Direct-seeded rice	264.8	22.1	173.5	15.77	24.46	5.47	6.69	45.13
Transplanted rice	288.3	22.4	185.8	15.24	24.37	5.65	6.88	45.22
SEm±	5.06	0.29	3.44	0.172	0.169	0.030	0.078	0.331
CD (P=0.05)	12.3	NS	8.4	0.42	NS	0.07	NS	NS
Nutrient management in rice								
Inorganic	270.8	21.7	183.2	16.65	23.91	5.35	6.61	45.03
Organic	237.7	22.1	165.5	14.54	24.81	5.26	6.66	44.23
INM	321.0	22.9	190.2	15.32	24.53	6.06	7.09	46.27
SEm±	6.20	0.36	4.21	0.211	0.207	0.037	0.096	0.405
CD (P=0.05)	15.1	0.9	10.3	0.51	0.51	0.09	0.23	0.99

*Details of nutrient management are given under Materials and Methods

highest straw yield (7.09 t/ha), as compared to organic and inorganic practices, which in turn were at par with each other. Harvest index of rice was not affected by the rice-establishment methods. However, the value was lower in DSR than TPR. The INM practice in rice improved the harvest index over inorganic and organic practices.

Groundnut: Carryover effect of DSR favourably influenced the pods/plant (18.0), pod weight/plant (16.2 g), kernels/pod (1.86), 100-kernel weight (64.4 g) and shelling out turn (72.5%) in succeeding groundnut crop as compared to that grown after TPR resulting in 15.8% higher pod yield (Table 2). This was primarily due to deterioration of soil physical condition by breakdown of capillary pores, destruction of soil aggregates and dispersion of fine clay particles increasing bulk density of the surface layer and formation of hard pan at shallow depth through puddling in TPR that creates soil physical condition detrimental to the succeeding non-rice crop in rice-based cropping systems (Bandyopadhyay *et al*., 2019).

Residual effect of organic nutrient management in rice was the maximum, closely followed by INM, and the lowest was with inorganic practice as was reflected in terms of pods/plant, pod weight/plant, kernels/pod and 100-kernel weight. All these culminated in the highest pod yield (2.47 t/ha), which was 4.2 and 16.5% higher than the INM and inorganic practice in rice crop respectively. This might be owing to availability of continuous and balanced supply of nutrients for a prolonged period because of residual effect of organic and INM, both comprising the green-manuring crop in preceding rice. This corroborates the findings of Prasad *et al*., (2002) and Saini *et al*., (2019).

The INM practice in groundnut comprising 75% STBN (inorganic) + 25% STBN through FYM @ 1.63 t/ha + 0.2 LR @ 0.38 t lime/ha + biofertilizers (*Rhizobium* + PSB) + 100% P_2O_5 + 100% K_2O increased the number of pods/plant (18.2), pod weight/plant (16.8 g), kernels/pod (1.94 g) and 100-kernel weight (67.0 g), resulting in 11.4 and 18.1% higher pod yield over 100% STBF and 75% STBF respectively. This might be because of increased solubility and availability of N in the rhizosphere owing to biofertilizers, improvement of soil *p*H with lime and that of physico-chemical properties owing to FYM, and instant availability of nutrients from inorganic fertilizers. Our results confirm the findings of Singh *et al*., (2013) and Singh *et al*., (2021). Soil management with lime or organic manures can alter soil properties such as *p*H and stimulate micronutrient bioavailability and crop uptake.

Haulm yield of groundnut crop after DSR was 2.9% higher than that after TPR. Residual effect of INM practice in rice improved the haulm yield of succeeding groundnut crop, which was on a par with that of organic nutrition in rice but was 10.6% higher than inorganic practice. Integrated use of organics and inorganics in groundnut crop resulted in the highest haulm yield, but was at par with the other 2 practices. Groundnut crop grown after DSR exhibited higher harvest index than after TPR. Organic nutrition to rice crop and INM in groundnut improved the harvest index values as compared to the other treatments.

Table 2. Effect of rice-establishment methods and nutrient management in rice-groundnut system on yield attributes and yield of groundnut (pooled data of 2 years)

Treatment	Pods/ plant	Pod weight/plant (g)	Kernels/ pod	100-kernel weight (g)	Shelling outturn (%)	Pod yield (t/ha)	Haulm yield (t/ha)	Harvest index (%)
Rice-establishment method								
Direct-seeded rice	18.0	16.2	1.86	64.4	72.5	2.49	3.59	41.13
Transplanted rice	16.0	14.3	1.65	63.1	71.3	2.15	3.49	38.26
SEm±	0.46	0.41	0.048	1.40	0.85	0.025	0.053	0.446
CD (P=0.05)	1.4	1.2	0.14	NS	NS	0.07	NS	1.32
Nutrient management in rice								
Inorganic	16.1	13.8	1.68	60.7	71.3	2.12	3.31	38.82
Organic	18.3	16.8	1.84	66.3	72.4	2.47	3.65	40.48
INM	16.7	15.1	1.73	64.2	72.1	2.37	3.66	39.63
SEm±	0.57	0.50	0.058	1.70	1.05	0.030	0.065	0.546
CD (P=0.05)	1.7	1.5	0.18	NS	NS	0.09	0.19	NS
Nutrient management in groundnut								
75% STBF (inorganic)	16.1	13.7	1.58	60.0	70.9	2.15	3.43	38.66
100% STBF (inorganic)	16.8	15.1	1.74	64.2	71.8	2.28	3.57	39.03
INM	18.2	16.8	1.94	67.0	73.1	2.54	3.62	41.24
SEm±	0.48	0.42	0.050	1.10	1.11	0.032	0.107	0.726
CD (P=0.05)	1.4	1.2	0.15	3.2	NS	0.09	NS	2.06

*Details of nutrient management are given under Materials and Methods

System yield and production efficiency

The DSR resulted in 6.8% higher system yield (12.51 t rice-equivalent yield/ha) than TPR. Though TPR gave only 3.3% higher grain yield than DSR (Table 3), groundnut crop after DSR provided about 15.8% higher pod yield than after TPR. Direct seeding in rice is reported to resolve the edaphic conflicts between rice and the subsequent non-rice crop and enhances yield of succeeding winter crops as compared to transplanted rice owing to the deterioration in soil physical conditions due to puddling in the latter (Farooq *et al.,* 2011).

The INM practice in rice resulted in, on an average, 4.2 and 12.6% higher system yield (12.76 t REY/ha) over organic and inorganic practices, respectively, because of higher yield of rice under INM than organic treatment, but similar yield of groundnut under residual effect of both organic and INM practice in preceding rice crop. Similarly, INM practice in groundnut improved the system yield (12.84 t REY/ha) by 7.4 and 11.2% over 100 and 75% STBF, respectively, because of corresponding increase in groundnut yield by 11.4 and 18.1% in conformity with Singh *et al*., (2013). The results are in agreement with the findings of Prasad *et al*., (2002). The DSR enhanced production efficiency of the system by 6.9% over TPR, and the INM practice in rice increased the yield by 4.2 and 12.7% over organic and inorganic, respectively, almost in line with the respective improvement in system yield. The INM practice in groundnut also resulted in the highest production efficiency, which was significantly higher than other nutrient-management approaches in groundnut (Chavan *et al*., 2014).

Profitability

The DSR based rice–groundnut cropping system (Table 3) fetched higher gross returns (₹240.4 × 10^3/ha), net returns (₹97.2 × 10^3/ha), benefit:cost ratio (1.71) and profitability (₹266.4/ha/day) over TPR owing to lower cost of cultivation (man-days) and higher system yield. The results confirm the findings of Bohra and Kumar (2015). Organic sources of nutrient to rice resulted in higher cost of cultivation of the system due to higher cost of organic manures. But INM in rice resulted in the highest average gross returns (₹245.5 × 10^3/ha), net returns (₹108.9 × 10^3/ha), benefit:cost ratio (1.80) and profitability (₹298.5/ha/day), because of higher yield. Similarly, INM to groundnut crop incurred the highest cost of cultivation of the system amongst different nutrient-management practices but fetched higher average gross returns, net returns, BCR and system profitability over 75% STBF and 100% STBF owing to higher system yield under INM, which might have negated the relatively higher cost of organic sources of nutrients. These findings are in line with those of Samant (2015) in rice–brinjal cropping system. Sharma *et al*., (2019) reported higher grain yield and net returns with INM over inorganic and organic practices in isolation and fetched more net returns in rice and wheat, respectively in rice–wheat system.

Table 3. Effect of rice-establishment methods and nutrient management in rice-groundnut system on system productivity and profitability (pooled data of 2 years)

Treatment	System yield (t REY/ha)	Production efficiency (kg/REY/ha/day)	Cost of cultivation (×10³₹/ha)	Gross returns (×10³₹/ha)	Net returns (×10³₹/ha)	Benefit: cost ratio	System profitability (₹/ha/day)
Rice-establishment method							
Direct-seeded rice	12.51	34.28	143.2	240.4	97.2	1.71	266.4
Transplanted rice	11.71	32.08	149.7	225.6	75.9	1.52	207.9
SEm±	0.068	0.187					
CD (P=0.05)	0.20	0.55					
Nutrient management in rice							
Inorganic	11.33	31.03	130.1	218.2	88.1	1.68	241.3
Organic	12.25	33.55	172.7	235.4	62.7	1.36	171.7
INM	12.76	34.96	136.5	245.5	108.9	1.80	298.5
SEm±	0.084	0.229					
CD (P=0.05)	0.25	0.68					
Nutrient management in groundnut							
75% STBF (inorganic)	11.55	31.63	140.0	222.1	82.1	1.61	224.9
100% STBF (inorganic)	11.95	32.75	145.2	230.0	84.8	1.61	232.4
INM	12.84	35.17	154.2	247.0	92.7	1.62	254.1
SEm±	0.089	0.244					
CD (P=0.05)	0.25	0.70					

Price of produce @ ₹/t (rice grain,18, 680; rice straw, 1,000; groundnut pod, 52, 750); man-days, ₹308

*Details of nutrient management are given under Materials and Methods

Soil health

Physico-chemical properties: Physico-chemical properties of soil after completion of 2 years of crop cycle (Table 4) revealed that, cropping for 2 cycles marginally increased the bulk density, *p*H and organic carbon content of soil over the initial values. Active soil aeration with vigorous root development and facilitated rhizosphere might be the cause of reduced bulk density in DSR (1.53 Mg/m^3), organic nutrition in rice (1.50 Mg/m^3) and INM in groundnut (1.53 Mg/m^3). Puddling in transplanted rice increases soil bulk density because of destruction of soil aggregates and dispersion of fine clay particles (Bandyopadhyay *et al*., 2019), whereas an addition of organic manure in form of green manuring and FYM under organic nutrition and INM practice decreases it by improving soil organic carbon, thereby increasing porosity. Soil *p*H also varied within a narrow range with the maximum in inorganic nutrition to rice (5.56) and INM in groundnut (5.65) as against the initial value. Soil organic carbon content increased from initial value and attained the maximum with organic management in rice (0.68%) and INM in groundnut (0.63%).

The cropping system improved the available soil N and P content but declined that of K as compared to the corresponding initial values. Improvement in soil N and P status was more in DSR than TPR, and available N was the maximum with the organic nutrition to rice (214.3 kg/ha), while that of P was with the INM practice in the crop (20.1 kg/ha). The INM in groundnut resulted in the maximum enhancement in available soil N (216.5 kg/ha) and P (21.8 kg/ha) followed by 100% and 75% STBF in sequence. Addition of organic manures and biofertilizers resulted in higher N owing to its build up by continuous use of organic nutrient source and with inorganic phosphate availability. Lower available K in soils after 2 cropping cycles compared to the initial value was owing to exhaustive removal of K by the crops and the values were higher in TPR and INM in both rice and groundnut as compared to other comparable treatments in the experiment. Senthivalavan and Ravichandran (2020) also reported similar results in rice–blackgram cropping system.

Biological properties: Two years of crop cycle increased the population of bacteria and actinomycetes, but declined that of fungi as compared to the corresponding initial values (Table 4). DSR resulted in higher actinomycetes population (7.3 ×10^{6}cfu/g soil), but similar bacteria and fungi than TPR owing to better nutrient availability, nutrient cycling and solubilizing insoluble forms of nutrients as a result of better rhizosphere formation of crops under DSR (Pandey *et al*., 2010). Organic management in rice was better than INM and inorganic practice in formation of microbial colonies (bacteria 10.4 ×10^6, actinomycetes 8.2 ×10^6 and fungi 8.1 ×10^4 cfu/g soil), which might be because of better effect of sole organics on microbial population and their activities than when were applied in conjunction with inorganics. Similarly, the INM practice in groundnut including inorganic fertilizers, FYM, lime and biofertilizers (*Rhizobium* + PSB) registered higher microbial population than the inorganic practices (75% and 100% STBF) in the crop. All these have enhanced the organic carbon content and facilitated conducive rhizosphere, resulting in effective

Table 4. Effect of rice-establishment methods and nutrient management in the system on soil physico-chemical and biological properties at the end of 2 years

Treatment	Physico-chemical						Biological (microbial population)		
	Bulk density (Mg/m^3)	*p*H	Organic carbon (%)	Available nutrient (kg/ha)			Bacteria (×10^{6}cfu/g soil)	Actinomycetes (×10^{6}cfu/g soil)	Fungi (×10^{4}cfu/g soil)
				N	P	K			
Rice-establishment method									
Direct-seeded rice	1.53	5.36	0.62	215.5	19.9	170.6	9.8	7.3	6.1
Transplanted rice	1.54	5.57	0.60	197.6	17.6	182.3	9.6	7.0	6.0
SEm±	0.03	0.006	0.018	0.43	0.04	3.76	0.23	0.21	0.21
CD (P=0.05)	NS	0.02	NS	1.4	0.1	NS	NS	NS	0.65
Nutrient management in rice									
Inorganic	1.57	5.56	0.56	195.2	18.0	171.7	8.7	6.1	5.0
Organic	1.50	5.30	0.68	214.3	18.3	173.9	10.4	8.2	8.1
INM	1.54	5.53	0.58	210.1	20.1	183.7	10.0	7.1	5.0
SEm±	0.04	0.008	0.021	0.53	0.05	4.61	0.28	0.25	0.25
CD (P=0.05)	NS	0.02	0.07	1.7	0.2	NS	0.88	0.79	0.79
Nutrient management in groundnut									
75% STBF (inorganic)	1.54	5.35	0.59	198.5	16.7	169.0	9.3	6.7	5.9
100% STBF (inorganic)	1.54	5.40	0.61	204.6	17.8	177.2	9.8	7.1	6.0
INM	1.53	5.65	0.63	216.5	21.8	183.1	10.0	7.6	6.2
SEm±	0.01	0.008	0.011	0.24	0.07	0.33	0.03	0.02	0.01
CD (P=0.05)	NS	0.02	0.03	0.7	0.2	1.0	0.09	0.05	0.03
Initial status	1.43	5.28	0.57	187.5	15.4	189.4	4.0	6.1	8.0

*Details of nutrient management are given under Materials and Methods

below-ground activities (Shwetha *et al*., 2011).

Based on the experimental results obtained from 2 year study, it can be concluded that integrated nutrient management practices under direct-seeded rice, followed by 75% soil test-based nitrogen (18.75 kg/ha) through inorganic source + 25% STBN through 1.63 t FYM/ha + 0.2 LR @ 0.38 t lime/ha + biofertilizers (*Rhizobium* and phosphate-solubilizing bacteria) to succeeding groundnut crop is the recommended practice for higher productivity, profitability and improvement in physico-chemical and biological properties of soil in rice–groundnut cropping system.

REFERENCES

Bandyopadhyay, K.K., Sarangi, A., Kumar, R.D. and Singh, D.K. 2019. Effect of puddling and direct sowing of rice on soil physical health and water productivity of rice–wheat cropping system under different irrigation regimes. *Journal of the Indian Society of Soil Science* **67**(2): 160–173.

Bastola, A. 2020. A review on effect of establishment methods on growth, yield and yield attributes of rice and on succeeding crops after rice. *International Journal for Research in Applied Sciences and Biotechnology* **7**(6): 134–139.

Biswas, P.,Ghosh, M., Pal, S., Bandopadhyay, P.K. and Saha, A.2023. Effect of organic and inorganic nutrient sources on growth, yield and economics of aromatic rice (*Oryza sativa*) in Gangetic delta of West Bengal. *Indian Journal of Agronomy* **68**(1): 93–96.

Bohra, J.S. and Kumar, R. 2015. Effect of crop establishment methods on productivity, profitability and energetics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system. *Indian Journal of Agricultural Sciences* **85** (2): 217–223.

Chavan, A.P., Jain, N.K. and Mahadkar, U.V. 2014. Direct and residual effects of fertilizers and biofertilizers on yield, nutrient uptake and economics of groundnut (*Arachis hypogaea*)–rice (*Oryza sativa*) cropping system. *Indian Journal of Agronomy* **59**(1): 53–58.

DES. 2020. *Pocket Books of Agricultural Statistics 2020*, Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Government of India, New Delhi.

Deep, M., Kumar, R.M. and Saha, S. 2018. Rice-based cropping systems for enhancing productivity of foodgrains in India: decadal experience of AICRP. *Indian Farming* **68**(01): 27–30.

Farooq, M., Siddique, K.H.M., Rehman, H., Aziz, T., Lee Dong-Jin and Wahid, A. 2011. Rice direct seeding: Experiences, challenges and opportunities. *Soil and Tillage Research* **111**: 87–98.

Gangwar, B., Katiyal, V. and Anand, K.V. 2003. Productivity, stability and efficiency of different cropping sequences in Maharashtra. *Indian Journal of Agricultural Sciences* **73** (9): 471–477.

Ghosh, M., Ashiq, W., BhogilalVasava, H., Gamage, D.N.V., Patra, P.K. and Biswas, A. 2021. Short-term carbon sequestration and changes of soil organic carbon pools in rice under integrated nutrient management in India. *Agriculture* **11**(4): 1–14.

Kundu, R., Mondal, M., Garai, S., Mondal, R. and Poddar, R. 2020. Bio-efficacy of post-emergence herbicides in *boro* rice nursery as well as main field and their residual effects on non-target microorganisms. *Oryza* **57**(3): 199–210.

Mohapatra, S., Tripathy, S.K. and Mohanty, A.K. 2022. Evaluation of fertilizer doses under different planting methods of rice (*Oryza sativa*) in west central table land zone of Odisha. *Indian Journal of Agronomy* **67**(2): 123–128.

Pandey, M.K., Verma, A., Sirmaur, A. and Dwivedi, A. 2018. Study on the effect of different rice establishment techniques on crop growth, yield and energy assessment and water productivity in rainfed conditions. *Journal of Pharmacognosy and Phytochemistry* **7**(1): 501–505.

Pandey, M.P., Verulkar, S.B. and Sharma, D. 2010. Rice research: Past achievements, present scenario and future thrust. *Indian Journal of Agricultural Sciences* **80**(6): 447–469.

Patra, A.K., Garnayak, L.M., Mishra, K.N., Mohanty, T.R., Mohapatra, B.K. and Swain, S.K. 2019. Balanced fertilization in rice (*Oryza sativa*)–groundnut (*Arachis hypogaea*) cropping system. *Indian Journal of Agronomy* **64**(3): 293–297.

Prasad, P.V.V., Satyanarayana, V., Murthy, V.R.K. and Boote, K.J. 2002. Maximising yields in rice–groundnut cropping sequence through integrated nutrient management. *Field Crops Research* **75**(1): 9–21.

Saini, P.K., Yadav, R.K. and Yadav, C. 2019. Green manures in agriculture: A review. *Bhartiya Krishi Anusandhan Patrika* **34**(1): 1–10.

Salma, D., Venkaiah, K. and Naidu, M.V.K. 2018. Impact on soil properties and yield of rainfed groundnut mono cropping system (*Arachis hypogaea* L.) under long term application of manure and fertilizers. *International Journal of Current Microbiology and applied Sciences* **7**(12): 1,346–1,360.

Samant, T.K. 2015. System productivity, profitability, sustainability and soil health as influenced by rice-based cropping systems under Mid-Central Table Land zone of Odisha. *International Journal of Agriculture Sciences* **7**(11): 746–749.

Senthivalavan, P. and Ravichandran, M. 2020. Post harvest soil fertility status of rice-black gram cropping system in *Typic Haplusterts* influenced by integrated nutrient management and crop cultivation techniques. *Plant Archives* **20**(10): 2,644–2,649.

Sharma, S., Padbhushan, R. and Kumar, U. 2019. Integrated nutrient management in rice-wheat cropping system: An evidence on sustainability in the Indian subcontinent through meta-analysis. *Agronomy* **9**(2): 68–71.

Shwetha, S., Narayana, J., Shwetha, B.V. and Girish, R. 2011. Effect of vermicompost on soil bacterial and fungal populations in rice crop (*Oryza sativa*). *Mysore Journal Agricultural Sciences* **45**(1): 7–10.

Singh, G.P., Singh, P.L. and Panwar, A.S. 2013. Seed yield, quality and nutrient uptake of groundnut (*Arachis hypogaea*) as affected by integrated nutrient management in mid hill attitude of Meghalaya, India. *Legume Research* **36**(2): 147–152.

Singh, N., Joshi, E., Sasode, D.S., Rawat, G.S. and Tiwari, S. 2021. Response of rainy-season groundnut (*Arachis hypogaea*) to varying fertility levels and bioformulations. *Indian Journal of Agronomy* **66**(2): 241–245.

Tripathi, R.P., Sharma, P. and Singh, S. 2005. Tillage index: An approach to optimize tillage in rice–wheat system. *Soil and Tillage Research* **80**: 125–137.