PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.8288

eISSN 2348-1900

RESEARCH ARTICLE

Efficacy of nano fertilizer application to groundnut in rice-groundnut cropping system

Sagar Pradhan[1]*, Prasannajit Mishra[1], Bijay Kumar Mohapatra[1], Narayan Panda[2], Araya Kumar Biswamohan Mohapatra[3] & Palla Madhu Babu[2]

[1]Department of Agronomy, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, India
[2]Department of Soil Science and Agricultural Chemistry, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, India
[3]Department of Agricultural Meteorology, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, India

*Correspondence email - sagarpradhan906@gmail.com

Received: 15 March 2025; Accepted: 25 April 2025; Available online: Version 1.0: 10 May 2025

Cite this article: Sagar P, Prasannajit M, Bijay KM, Narayan P, Araya KBM, Palla MB. Efficacy of nano fertilizer application to groundnut in rice-groundnut cropping system . Plant Science Today (Early Access). https:/doi.org/10.14719/pst.8288

Abstract

An experiment was conducted at the Agronomy main research farm, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, during the Kharif and Rabi seasons of 2022–23 and 2023–24. The research was worked out in randomized block design (RBD) during kharif and split plot design (SPD) during rabi. The rice variety “Kalinga Dhan 1204” was transplanted in kharif with seven treatments: T_1- Control (no fertilizer), T_2- full soil test based nitrogen recommendation (STBNR) through inorganic sources, T_3- full STBNR through organic sources (FYM), T_4- full STBNR through 50 % organic (FYM) + 50 % inorganic sources, T_5- full STBNR through 25 % organic (FYM) + 75 % inorganic sources, T_6- 50 % N through inorganic sources + 2 nano urea spray (tillering & PI stage), T_7- 75% N through inorganic sources + 2 nano urea spray (tillering & PI stage). During rabi season each main plot divided into 3 sub plots and groundnut (variety- Kadiri lepakshi) was sown with 3 treatments: Z_1-100 % recommended dose of fertilizer (RDF), Z_2-75 % RDF+ 2 nano DAP spray, Z_3- 75 % RDF+ 2 nano di ammonium phosphate (DAP) spray + Phosphorus solubilizing bacteria (PSB). Pooled data revelled that highest number of panicles per square meter (393.17), total number of grains per panicle (176.83), test weight (25.27), grain yield (6.64 t ha^{-1}), straw yield (7.45 t h^{-1}) and harvest index (47.13 %) of rice were obtained with full STBNR (25 % organic (FYM) + 75 % inorganic). Among different treatment combinations, highest system yield (13.85 t rice equivalent yield ha^{-1}), system gross return (Rs. 303807), system net return (Rs. 164039) and system B/C ratio (2.17) were obtained with T_5Z_3 combinations.

Keywords: groundnut; rice; nano urea; nano DAP

Introduction

Rice (*Oryza sativa* L.) is a staple food for nearly two-thirds the population in the world. It is cultivated 165 million hectares worldwide, with an annual production of approximately 523.9 million tonnes (on a milled basis). Near about 90 % of the global rice cultivation and production is from Asian countries (1). Over the past five years, production increases have been attributed to both expanded cultivation areas and higher yields. China and India together account for nearly 50 % of the world’s total rice production. In the 2023-24 estimates, India cultivates rice across roughly 43.5 million hectares, producing about 130 million metric tons with an average yield of nearly 3000 kg per hectare. India ranks as the second-largest producer globally, following China. In Odisha, rice is grown at approximately 4.2 million hectares, generating about 9 million metric tons of production with a productivity of around 2200 kg per hectare (2). However, the country's low productivity poses a concern for over 60 % of the population that relies on rice for their food and nutritional needs (3). The incorporation of oilseeds and legumes into rice-based cropping systems significantly alters their economic dynamics. These crops are gaining increased attention due to their relatively low production levels and higher market values (4). In Odisha, rice is cultivated in medium and lowlands. In the year 2023 out of total cultivated area of 6.18 million hectares, kharif rice area was 4.06 million hectares. Prominent low land verities are Swarna, CR Dhan 510, CR Dhan 810 and Lalat (150-165 days duration), while major medium land verities are Pratikshya, CR Dhan 309, Khandagiri and Ajay (130-145 days duration). Major fertilizers used in rice are urea, di ammonium phosphate (DAP) and muriate of potash (MOP).

Peanut (*Arachis hypogaea* L.) is a leguminous oilseed and is widely cultivated in India, with an average yield of 1422 kg/ha. India ranks first globally in groundnut acreage and is the second-largest groundnut producer after China, with an estimated production of 67 lakh tonnes. In 2023, groundnut was cultivated in 1.10 lakh hectares in Odisha (2). In Odisha, several major groundnut (peanut) varieties are cultivated, suitable for different agro-climatic conditions. These varieties are selected based on their adaptability, disease resistance, oil content and yield potential. Prominent groundnut verities are Dharani, AK 12-24 and Kadiri.

The rice-groundnut cropping system holds significant importance in Odisha. Rice is the dominant crop, occupying nearly 67 % of the total cultivable area during the rainy (kharif) season. Groundnut, the primary oilseed crop, is cultivated on approximately 0.26 million hectares, with the winter (rabi) season contributing to about 69 % of the total groundnut area. Both crops are nutrient-intensive and highly sensitive to climate variations. However, the sustainability and productivity of this system are increasingly under threat due to soil degradation caused by improper nutrient management practices (5).

Continuous rice monocropping and over-reliance on chemical fertilizers can lead to soil quality degradation. It is crucial to recommend appropriate rice-based cropping systems and nutrient management strategies to achieve higher yields and income while preserving soil fertility. Excessive use of high-analysis fertilizers often results in nutrient imbalance, depriving crops of essential micronutrients. This issue can be mitigated by adopting a rice-legume cropping system. Incorporating organic manures, nano fertilizers and biofertilizers into rice-groundnut systems not only improve soil quality but also benefits subsequent crops because of their residual effects. Integrated nutrient management (INM) practices in rice cultivation can reduce the fertilizer requirement for the following crop to a suboptimal level, such as 75 % of the recommended fertilizer dose (RDF). By integrating various nutrient sources, crops' nutrient needs can be efficiently met, enhancing productivity. Combining organic with inorganic fertilizers promotes better yield, soil health and nutrient-use efficiency (6).

Low productivity in groundnut cultivation is often attributed to the use of imbalanced plant nutrients particularly phosphorus. The application of manures, biofertilizers and combination of normal as well as nano fertilizers plays a critical role in influencing the availability of nutrients and altering the soil's physical properties, which significantly affect groundnut growth (7). However, comprehensive research on balanced nutrient management for groundnut, especially within the rice-groundnut cropping system, remains limited and scattered. Considering all the factors, a field experiment was worked out on the rice-groundnut cropping system to find out the effects of integrated nutrient management practices on productivity and profitability of the system.

Material and Methods

The experiment was conducted at the Agronomy main research farm, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, during the Kharif and Rabi seasons of 2022-23 and 2023-24. The farm is positioned at latitude of $20^0$15'53.7"N and longitude of $85^0$52'45.78"E, with an elevation of 25.9 meters above mean sea level (MSL). The site is located approximately 64 kilometers from the Bay of Bengal, falling within the East and Southeastern Coastal Plain Agro-climatic zone of Odisha.

The research was worked out in randomized block design (RBD) during kharif and split plot design (SPD) during rabi. The rice variety "Kalinga Dhan 1204" was transplanted in kharif with seven treatments: T_1- Control (no fertilizer), T_2- full soil test based nitrogen recommendation (STBNR) through inorganic sources, T_3- full STBNR through organic sources (FYM), T_4- full STBNR through 50 % organic (FYM) + 50 % inorganic sources, T_5- full STBNR through 25 % organic (FYM) + 75 % inorganic sources, T_6- 50 % N through inorganic sources + 2 nano urea spray (tillering & PI stage), T_7- 75 % N through inorganic sources + 2 nano urea spray (tillering & PI stage). During rabi season each main plot divided into 3 sub plots and groundnut (variety- Kadiri lepakshi) was sown with 3 treatments: Z_1-100 % recommended dose of fertilizer (RDF), Z_2-75 % RDF+ 2 nano DAP spray (30DAS & 45DAS), Z_3- 75 % RDF+ 2 nano DAP spray (30 DAS & 45 DAS) + phosphorus solubilizing bacteria (PSB). Data on yield parameters were collected at harvest from five randomly selected plants in each plot and averaged to obtain replicated data. The economic analysis was conducted by assessing the cost of cultivation, gross revenue, net profit and the benefit-to-cost ratio. The data were analysed using pooled data from two years, as per the prescribed methodology and subjected to standard analysis of variance (ANOVA). A randomized block design was used for rice, while a split-plot design was applied for groundnut and the system.

Yield attributes and yield of rice

Number of panicles per square meter: After harvest, total number of panicles per square meter was counted for each treatment and denoted as the number of panicles per square meter.

Total number of grains per panicle: Five panicles were selected randomly from each plot and total number of grains per panicle was counted. Average number of grains per panicle for each treatment, across three replications, indicates the average grains per panicle for each individual treatment.

Test weight of rice: From each treatment 1000 filled grains were collected and dried in an oven at 60 °C until a constant weight was achieved. It indicates the test weight for each treatment.

Grain and straw yield of rice: Followed by harvesting of rice, the samples were bundled and weighed to determine the total biomass yield. The bundles were then threshed. The grain and straw yields were recorded separately for each treatment.

Harvest index of rice: Harvest Index was calculated by using the following formulae;

$$\text{Harvest index} = \frac{\text{Grain yield}}{(\text{Grain yield} + \text{Straw yield})} \times 100$$

Yield attributes and yield of groundnut

Number of pods per plant and pod weight per plant: Pods from five randomly selected plants from each plot were counted and averaged to determine the number of pods per plant. These pods were then dried in air and weighed and the average weight was calculated.

Kernels per pod: Five pods were randomly selected from each plot and manually shelled. The number of kernels from each pod was then counted, averaged over the ten pods and expressed as kernels per pod.

Pod length: Five pods were randomly selected from each plot and their lengths were measured. Lengths were averaged and expressed as pod length.

Test weight: Two batches of 1000 kernels were counted from each plot after shelling. The kernels were weighed and averaged to obtain the test weight.

Pod yield: After harvesting the pods were detached and dried for 3-5 days. They were then weighed and the weight was converted to tons per hectare (t ha^{-1}).

Haulm yield: After detachment of pods, the plants were sun-dried for an additional 2-3 days. They were then weighed and the stover was converted to tons per hectare (t ha^{-1}).

Shelling percent: From each plot, 100 grams of clean pods were weighed. After shelling, the kernels were weighed and shelling percent was calculated using the following formulae;

$$\text{Shelling percent} = \frac{\text{Kernel weight}}{\text{pod weight}} \times 100$$

Harvest index: Harvest index was worked out using the following formulae;

$$\text{Harvest index} = \frac{\text{pod yield}}{(\text{pod yield} + \text{Haulm yield})} \times 100$$

System yield and economics

Rice equivalent yield of system: It was worked out using the following formulae;

$$\text{Rice equivalent yield of system} = \text{Yield of rice} + \frac{(\text{Yield of groundnut} \times \text{Price of groundnut})}{\text{Price of rice}}$$

System gross return: It was worked out using the following formulae;

System gross return = Rice equivalent yield of system x Price of rice

System net return: It was worked out using the following formulae;

System net return = System gross return - Cost of cultivation

Benefit to cost ratio (B/C ratio): It was worked out using the following formulae;

$$\text{B/C ratio} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

Results and Discussion

Effect of integrated nutrient management on yield attributes and yield of rice

Among different treatments highest number of panicles per square meter (393.17), total number of grains per panicle (176.83), test weight (25.27) was obtained with full STBNR (25 % organic (FYM) + 75 % inorganic) applied plot and it is followed by plot treated with full STBNR through 50 % organic (FYM) + 50 % inorganic sources. Lowest number of panicles per square meter (289.67), total number of grains per panicle (146.00), test weight (22.97) was recorded with control (no fertilizer), as shown in Table 1. The implementation of integrated nutrient management practices significantly affects both grain and straw yield (Table 1). Highest grain yield, straw yield and harvest index (6.64 t ha^{-1}, 7.45 t h^{-1} and 47.13 %) were recorded with full STBNR (25 % organic (FYM) + 75 % inorganic) whereas lowest grain yield (2.96 t ha^{-1}, 3.69 t ha^{-1} and 44.60 %) w recorded with control (no fertilizer). Similarly grain yield recorded with treatment 75 % N inorganic sources + 2 nano urea spray (5.59 t ha^{-1}) was also found to be at par with grain yield obtained with full STBNR through inorganic sources (5.49 t ha^{-1}), as shown in Table 1.

The increased yield with 25 % or 50 % organic nutrient substitution could be attributed to the gradual release and sustained supply of essential nutrients throughout different growth stages. This steady nutrient availability supports optimal photosynthesis, leading to a greater number of effective tillers (more panicles with fertile grains), higher number of grains per panicle, improved test weight, increased grain yield, straw yield and harvest index (8, 9).

Nano urea's effectiveness is attributed to its smaller particle size, which increases the specific surface area and the number of fertilizer particles per unit area. This expanded surface area enhances interactions with the fertilizer, facilitating better penetration and nutrient absorption. As a result, the uptake efficiency improves, leading to a greater number of tillers (10).

Residual effect of integrated nutrient management in rice on yield attributes and yield of groundnut

Residual effect of integrated nutrient management in rice significantly affected yield attributes of subsequent groundnut crop. The residual impact of full STBNR through organic sources (FYM) in rice was the highest, followed closely by full STBNR (50 % organic (FYM) + 50 % inorganic), while the lowest effect was observed with control (no fertilizer). This was evident from parameters such as the number of pods per plant, pod weight per plant, kernels per pod, pod length and test weight. Highest number of pods per plant (14.79), pod weight per plant (13.59 g), seeds per pod (2.22), test weight (446.67 g) and pod length (4.28 cm) were obtained with residual effect of full STBNR through organic sources (FYM) in rice followed by number of pods per plant (13.83), pod weight per plant (12.63 g), seeds per pod (2.18), test weight (445.56 g) and pod length (4.22 cm) obtained with residual effect of full STBNR (50 % organic (FYM) + 50 % inorganic). Whereas lowest number of pods per plant (7.99), pod weight per plant (6.00 g), seeds per pod

Table 1. Effect of integrated nutrient management in rice on number of panicles m^{-2}, total number of grains $panicle^{-1}$, test weight, grain yield, straw yield and harvest index of rice

Particular / Integrated nutrient management	Number of panicles per square meter	Total number of grains per panicle	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1-Control (No fertilizer)	289.67	146.00	22.97	2.96	3.69	44.60
T_2-Full STBNR through inorganic sources	330.50	160.83	24.33	5.49	6.23	46.81
T_3-Full STBNR through organic sources (FYM)	305.33	155.67	23.53	4.49	5.40	45.31
T_4-Full STBNR (50% organic (FYM) + 50% inorganic)	353.33	168.50	24.60	6.19	7.07	46.69
T_5-Full STBNR (25% organic (FYM) + 75% inorganic)	393.17	176.83	25.27	6.64	7.45	47.13
T_6-50% N inorganic sources + 2 nano urea spray	312.00	159.17	23.37	4.51	5.44	45.33
T_7-75% N inorganic sources + 2 nano urea spray	337.50	161.33	24.08	5.59	6.29	47.02
SEm±	2.41	5.80	0.12	0.20	0.22	0.26
CD (P= 0.05)	8.35	17.87	NS	0.57	0.65	0.75

Values indicate mean of 3 replications; Pooled data indicate average of 2022-23,2023-24

SEm = Standard error of mean, CD = Critical difference

(1.82), test weight (439.89 g) and pod length (3.52 cm) were obtained with residual effect of control (no fertilizer) as depicted in Table 2.

Yield of groundnut was significantly affected by residual effect of integrated nutrient management in preceding rice crop. Highest pod yield (2.37 t ha^{-1}), shelling per cent (73.11 %), haulm yield (3.76 t ha^{-1}) and harvest index (38.65 %) were obtained with residual impact of full STBNR through organic sources (FYM), followed by pod yield (2.31 t ha^{-1}), shelling per cent (72.53 %), haulm yield (3.70 t ha^{-1}) and harvest index (38.39 %) obtained with residual effect of full STBNR (50 % organic (FYM) + 50 % inorganic). Lowest pod yield (1.41 t ha^{-1}), shelling per cent (69.47 %), haulm yield (2.77 t ha^{-1}) and harvest index (33.63 %) were obtained with residual effect of control (no fertilizer) as depicted in Table 3.

Better yield attributes and yield of groundnut because of FYM based treatments in rice mainly due to combined effect of organic and inorganic fertilizers that improved soil physical conditions to conserve moisture, gradual nutrient availability throughout the season and better microbial activity, resulting in better nutrient absorption, crop growth and pod formation (11- 14).

Direct effect of integrated nutrient management on yield attributes and yield of groundnut

The integrated nutrient management practices in groundnut have significant effect on yield attributes. Application of 75 % RDF with 2 nano DAP spray and PSB resulted in highest number of pods per plant (13.38), pod weight per plant (11.77 g), seeds per pod (2.16), test weight (445.21 g) and pod length (3.97 cm), whereas lowest number of pods per plant (11.13), pod weight per plant (9.20 g), seeds per pod (2.04), test weight (440.98 g) and pod length (3.72 cm) obtained from plot treated with 100 % RDF as depicted in Table 2.

The integrated nutrient management practices in groundnut have significant effect on yield. Application of 75 % RDF with 2 Nano DAP spray and PSB resulted in highest pod yield (2.07 t ha^{-1}), shelling per cent (72.02 %), haulm yield (3.46 t ha^{-1}) and harvest index (37.17 %), followed by pod yield (1.89 t ha^{-1}), shelling per cent (70.92 %), haulm yield (3.24 t ha^{-1}) and harvest index (36.56 %) obtained with application of 75 % RDF with 2 nano DAP spray. Application of 100 % RDF resulted in lowest pod yield (1.81 t ha^{-1}), shelling per cent (70.53 %), haulm yield (3.14 t ha^{-1}) and harvest index (36.36 %), as depicted in Table 3.

Table 2. Residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on number of pods per plant, pod weight per plant, number of seeds per pod, test weight and pod length of groundnut

Integrated nutrient management in rice	Number of pods per plant	Pod weight per plant (g)	Number of seeds per pod	Test weight (g)	Pod length (cm)
T_1-Control (No fertilizer)	7.99	6.00	1.82	439.89	3.52
T_2-Full STBNR through inorganic sources	12.37	10.72	2.16	444.33	3.77
T_3-Full STBNR through organic sources (FYM)	14.79	13.59	2.22	446.67	4.28
T_4-Full STBNR (50% organic (FYM) + 50% inorganic)	13.83	12.63	2.18	445.56	4.22
T_5-Full STBNR (25% organic (FYM) + 75% inorganic)	13.06	11.29	2.17	444.33	3.91
T_6-50% N inorganic sources + 2 nano urea spray	9.70	7.76	1.97	440.33	3.56
T_7-75% N inorganic sources + 2 nano urea spray	12.11	10.24	2.12	441.89	3.57
SEm±	0.28	0.28	0.03	1.60	0.04
CD (P= 0.05)	0.82	0.83	0.10	4.66	0.11
Integrated nutrient management in groundnut					
Z_1-100% RDF	11.13	9.20	2.04	440.98	3.72
Z_2-75% RDF + 2 Nano DAP spray	11.43	9.98	2.07	443.67	3.80
Z_3-75% RDF + 2 Nano DAP spray + PSB	13.38	11.77	2.16	445.21	3.97
SEm±	0.20	0.18	0.02	0.94	0.02
CD (P= 0.05)	0.57	0.52	0.07	2.66	0.07

Values indicate mean of 3 replications; Pooled data indicate average of 2022-23,2023-24

SEm = Standard error of mean, CD = Critical difference

Table 3. Residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on pod yield, shelling percent, haulm yield and harvest index of groundnut

Integrated nutrient management in rice	Pod yield (t ha^{-1})	Shelling percent (%)	Haulm yield (t ha^{-1})	Harvest index (%)
T_1-Control (No fertilizer)	1.41	69.47	2.77	33.63
T_2-Full STBNR through inorganic sources	1.84	70.62	3.17	36.67
T_3-Full STBNR through organic sources (FYM)	2.37	73.11	3.76	38.65
T_4-Full STBNR (50% organic (FYM) + 50% inorganic)	2.31	72.53	3.70	38.39
T_5-Full STBNR (25% organic (FYM) + 75% inorganic)	2.21	71.86	3.57	38.16
T_6-50% N inorganic sources + 2 nano urea spray	1.63	70.20	2.96	35.54
T_7-75% N inorganic sources + 2 nano urea spray	1.70	70.29	3.04	35.85
SEm±	0.05	0.26	0.09	0.11
CD (P= 0.05)	0.16	0.77	0.26	0.33
Integrated nutrient management in groundnut				
Z_1-100% RDF	1.81	70.53	3.14	36.36
Z_2-75% RDF + 2 Nano DAP spray	1.89	70.92	3.24	36.56
Z_3-75% RDF + 2 Nano DAP spray + PSB	2.07	72.02	3.46	37.17
SEm±	0.03	0.16	0.05	0.13
CD (P= 0.05)	0.10	0.46	0.15	0.36

Values indicate mean of 3 replications; Pooled data indicate average of 2022-23,2023-24

SEm = Standard error of mean, CD = Critical difference

Better yield attributes and yield of groundnut by the combined application of 75 % RDF with 2 Nano DAP spray and PSB to groundnut may be attributed to the ability of nano fertilizers to incorporate nanoscale mechanisms that regulate the controlled release of nitrogen and phosphorus, thereby enhancing nutrient uptake by crops (15). The increased concentration of nano fertilizers results in a larger surface area, facilitating better absorption of nutrients through foliar application. As a result, there was higher photosynthesis, hence promoting flower production and improving nutrient distribution during the reproductive stage. It leads to development of higher number of pods (16, 17). Similarly, higher pod yield, haulm yield and harvest index could be attributed to the combined influence of PSB inoculation and the foliar application of nano DAP, which likely improved nutrient availability in a balanced and sufficient manner during crucial growth stages resulting in better canopy spread and photosynthesis (18, 19).

Interaction effect of integrated nutrient management in rice and integrated nutrient management in groundnut on yield attributes and yield of groundnut

Interaction between main plot and sub plot found to have significantly effect on some of the yield attributes of groundnut like number of pods per plant, pod weight per plant and pod length. Among different treatment combinations, highest number of pods per plant (16.42), pod weight per plant (15.37 g) and pod length (4.47 cm) were recorded with T_3Z_3, followed by number of pods per plant (16.15) and pod weight per plant (15.00 g) obtained with T_5Z_3. Lowest number of pods per plant (7.39), pod weight per plant (5.03 g) and pod length (3.43 cm) were recorded with T_1Z_1, as depicted in Table 4.

Pod yield and haulm yield of groundnut were significantly affected by interaction between main plot and sub plot treatments. Among different treatment combinations, highest pod yield (2.55 t ha^{-1}) and haulm yield

Table 4. Interaction between residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on number of pods per plant, pod weight per plant, number of seeds per pod, test weight and pod length of groundnut

	Number of pods per plant			Pod weight per plant (g)			Number of seeds per pod			Test weight (g)			Pod length (cm)		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
T_1	7.39	8.15	8.42	5.03	6.28	6.68	1.75	1.87	1.85	438.83	440.50	440.33	3.43	3.52	3.60
T_2	11.78	11.70	13.63	10.48	10.65	11.02	2.13	2.17	2.17	441.67	445.67	445.67	3.80	3.63	3.88
T_3	13.95	14.00	16.42	12.03	13.38	15.37	2.17	2.20	2.28	444.33	445.83	449.83	4.10	4.27	4.47
T_4	12.38	13.12	16.00	11.12	12.17	14.62	2.15	2.17	2.23	444.00	445.50	447.17	4.07	4.20	4.40
T_5	11.43	11.58	16.15	9.32	9.55	15.00	2.10	2.10	2.30	442.67	444.00	446.33	3.65	3.87	4.22
T_6	9.38	9.50	10.22	7.23	7.75	8.30	1.90	1.90	2.10	436.83	441.17	443.00	3.52	3.57	3.58
T_7	11.58	11.95	12.80	9.17	10.11	11.43	2.07	2.10	2.18	438.50	443.00	444.17	3.50	3.55	3.65
SEm±		0.54			0.49			0.06			2.48			0.06	
CD (P= 0.05)		1.52			1.38			NS			NS			0.18	

***** SEm = Standard error of mean, CD = Critical difference

(T_1-Control (No fertilizer), T_2-Full STBNR through inorganic sources, T_3-Full STBNR through organic sources (FYM), T_4-Full STBNR (50% organic (FYM) + 50% inorganic), T_5-Full STBNR (25% organic (FYM) + 75% inorganic), T_6-50% N inorganic sources + 2 nano urea spray, T_7-75% N inorganic sources + 2 nano urea spray, Z_1-100% RDF, Z_2-75% RDF + 2 Nano DAP spray, Z_3-75% RDF + 2 Nano DAP spray + PSB)

(3.99 t ha^{-1}) were recorded with T_3Z_3. Whereas lowest pod yield (1.35 t ha^{-1}) and haulm yield (2.73 t ha^{-1}) were recorded with T_1Z_1, as depicted in Table 5.

Higher yield in T_5Z_3 interaction was mainly due to solubilization of occluded phosphorus by PSB as well as balanced nutrient availability to groundnut due to foliar application of nano DAP (18, 19).

System yield

Application of full STBNR (25% organic (FYM) + 75% inorganic) in rice resulted in highest system yield (13.02 t rice equivalent yield ha^{-1}), followed by system yield (12.87 t rice equivalent yield ha^{-1}) obtained with application of full STBNR (50 % organic (FYM) + 50 % inorganic). Lowest system yield (7.03 t rice equivalent yield ha^{-1}) was obtained from control (no fertilizer) plot as depicted in Table 6.

The integrated nutrient management practices in groundnut have significant effect on system yield. Application of 75 % RDF with 2 nano DAP spray and PSB to groundnut resulted in highest system yield (11.11 t rice equivalent yield ha^{-1}) followed by system yield (10.59 t rice equivalent yield ha^{-1}) obtained with application of 75 % RDF with 2 nano DAP spray. Application of 100 % RDF resulted in lowest system yield (10.36 t rice equivalent yield ha^{-1}), as depicted in Table 6.

System yield was significantly affected by interaction between main plot and sub plot treatments. Among different treatment combinations, highest system yield (13.85 t rice equivalent yield ha^{-1}) obtained with T_5Z_3. Whereas lowest system yield (6.87 t rice equivalent yield ha^{-1}) obtained with T_1Z_1, as depicted in Table 7.

Table 5. Interaction between residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on pod yield, shelling percent, haulm yield and harvest index of groundnut

	Pod yield (t ha^{-1})			Shelling percent (%)			Haulm yield (t ha^{-1})			Harvest index (%)		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
T_1	1.35	1.40	1.47	68.37	69.38	70.67	2.73	2.73	2.85	33.13	33.77	33.99
T_2	1.86	1.63	2.02	70.03	70.02	71.80	3.28	2.81	3.41	36.15	36.67	37.18
T_3	2.23	2.34	2.55	72.33	72.95	74.05	3.56	3.74	3.99	38.47	38.49	39.00
T_4	2.16	2.30	2.45	71.60	72.00	74.00	3.53	3.73	3.84	38.03	38.16	38.98
T_5	1.93	2.19	2.49	71.42	72.00	72.17	3.19	3.55	3.97	37.76	38.17	38.56
T_6	1.49	1.79	1.62	69.97	69.90	70.73	2.73	3.33	2.81	35.21	34.95	36.47
T_7	1.65	1.57	1.88	69.97	70.18	70.73	2.96	2.82	3.34	35.79	35.72	36.05
SEm±		0.09			0.43			0.14			0.33	
CD (P= 0.05)		0.25			NS			0.39			NS	

***** SEm = Standard error of mean, CD = Critical difference

(T_1-Control (No fertilizer), T_2-Full STBNR through inorganic sources, T_3-Full STBNR through organic sources (FYM), T_4-Full STBNR (50% organic (FYM) + 50% inorganic), T_5-Full STBNR (25% organic (FYM) + 75% inorganic), T_6-50% N inorganic sources + 2 nano urea spray, T_7-75% N inorganic sources + 2 nano urea spray, Z_1-100% RDF, Z_2-75% RDF + 2 Nano DAP spray, Z_3-75% RDF + 2 Nano DAP spray + PSB)

Table 6. Residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on system rice equivalent yield, system gross return, system net return and system B/C ratio

Integrated nutrient management in rice	REY system (t ha^{-1})	System gross return (Rs.)	System net return (Rs.)	System B/C ratio
T_1-Control (No fertilizer)	7.03	154846	25224	1.19
T_2-Full STBNR through inorganic sources	10.80	237390	101674	1.75
T_3-Full STBNR through organic sources (FYM)	11.36	248989	98688	1.65
T_4-Full STBNR (50% organic (FYM) + 50% inorganic)	12.87	282486	139333	1.97
T_5-Full STBNR (25% organic (FYM) + 75% inorganic)	13.02	285885	146989	2.06
T_6-50% N inorganic sources + 2 nano urea spray	9.24	203480	66690	1.49
T_7-75% N inorganic sources + 2 nano urea spray	10.51	231147	94067	1.69
SEm±	0.28	6200.71	6200.71	0.04
CD (P= 0.05)	0.82	18095.87	18095.87	0.13
Integrated nutrient management in groundnut				
Z_1-100% RDF	10.36	227917	90767	1.66
Z_2-75% RDF + 2 Nano DAP spray	10.59	232711	93145	1.66
Z_3-75% RDF + 2 Nano DAP spray + PSB	11.11	244039	104373	1.74
SEm±	0.10	2120.36	2120.36	0.02
CD (P= 0.05)	0.28	6006.10	6006.10	0.04

Values indicate mean of 3 replications; Pooled data indicate average of 2022-23,2023-24

SEm = Standard error of mean, CD = Critical difference

Table 7. Interaction between residual effect of integrated nutrient management in rice and direct effect of integrated nutrient management in groundnut on system rice equivalent yield, system gross return, system net return and system B/C ratio

	REY system (t ha^{-1})			System gross return (Rs.)			System net return (Rs.)			System benefit to cost ratio (B/C ratio)		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
T_1	6.87	7.00	7.21	151465	154279	158793	23487	23886	28300	1.18	1.18	1.22
T_2	10.86	10.19	11.34	238836	224183	249153	104763	87695	112565	1.78	1.64	1.82
T_3	10.94	11.26	11.87	240012	246877	260078	91354	95804	108905	1.61	1.63	1.71
T_4	12.46	12.86	13.29	273641	282302	291514	132132	138377	147490	1.93	1.96	2.02
T_5	12.22	12.98	13.85	268711	285138	303807	131458	145470	164039	1.96	2.04	2.17
T_6	8.84	9.69	9.19	194825	213317	202297	59679	75756	64635	1.44	1.55	1.47
T_7	10.36	10.12	11.03	227931	222881	242629	92494	85029	104677	1.68	1.62	1.76
SEm±		0.26			5610			5610			0.04	
CD (P= 0.05)		0.73			15891			15891			0.11	

* SEm = Standard error of mean, CD = Critical difference

(T_1-Control (No fertilizer), T_2-Full STBNR through inorganic sources, T_3-Full STBNR through organic sources (FYM), T_4-Full STBNR (50% organic (FYM) + 50% inorganic), T_5-Full STBNR (25% organic (FYM) + 75% inorganic), T_6-50% N inorganic sources + 2 nano urea spray, T_7-75% N inorganic sources + 2 nano urea spray, Z_1-100% RDF, Z_2-75% RDF + 2 Nano DAP spray, Z_3-75% RDF + 2 Nano DAP spray + PSB)

System economics

Application of full STBNR (25 % organic (FYM) + 75 % inorganic) in rice resulted in highest gross return (Rs. 285885), net return (Rs. 146989) and B/C ratio (2.06), followed by gross return (Rs. 282486), net return (Rs. 139333) and B/C ratio (1.97) obtained with application of full STBNR (50 % organic (FYM) + 50 % inorganic).

Application of 75 % RDF with 2 nano DAP spray and PSB to groundnut resulted in highest gross return (Rs. 244039), net return (Rs. 104373) and B/C ratio (1.74), followed by gross return (Rs. 232711), net return (Rs. 93145) and B/C ratio (1.66) obtained with application of 75 % RDF with 2 Nano DAP spray. Application of 100 % RDF resulted in lower gross return (Rs. 227917), net return (Rs. 90767) but same B/C ratio (1.66) as obtained with application of 75 % RDF with 2 nano DAP spray, as depicted in Table 6.

Among different treatment combinations, highest gross return (Rs. 303807), net return (Rs. 164039) and B/C ratio (2.17) were obtained with T_5Z_3. Whereas lowest gross return (Rs. 151465), net return (Rs. 23487) and B/C ratio (1.18) were obtained with T_1Z_1, as depicted in Table 7.

Application of full STBNR (25 % organic (FYM) + 75% inorganic) in rice resulted in highest rice equivalent yield (REY) and gross return of the system mainly due to higher yield of rice under it and 3rd highest pod yield of groundnut under its residual effect. Similarly higher REY and gross return of 75 % RDF with 2 Nano DAP spray and PSB treated plot was mainly due to highest pod yield. Higher net return and B/C ratio was mainly due to higher gross return and comparatively less increase in cost of cultivation due to application of full STBNR (25 % organic (FYM) + 75 % inorganic) to rice as well as application of 75 % RDF with 2 nano DAP spray and PSB to groundnut.

Conclusion

Based on results of the research conducted for two successive years, it can be inferred that application of full STBNR (25 % organic (FYM) + 75 % inorganic) to rice and application of 75 % RDF with 2 nano DAP spray and PSB to groundnut is the recommended practice to improve productivity and profitability of rice groundnut cropping system.

Acknowledgements

The authors sincerely thank the Vice-Chancellor, OUAT, Bhubaneswar, for his invaluable support and for providing the essential facilities during the research period. Their assistance has contributed significantly to the success of this study.

Authors' contributions

All the authors contributed to the above work, starting from designing the experiment, collecting data, assisting with statistical analysis, interpretation of results and manuscript preparation. Conceptualization of research was done by SP, PJM. Designing of the experiments was carried out by SP, PJM, BKM. Experimental materials were contributed by SP, NP, AKBM, PMB. Execution of field/lab experiments and data collection was done by SP, PJM, BKM, NP, AKBM. Analysis of data and technical guidance was given by SP, PJM. Original draft of the manuscript was prepared by SP, PJM, modifications and coordination was carried out by SP, PJM, BKM, NP, AKBM, PMB. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. FAO. 2023. The state of Food Security and Nutrition in the World 2023. Rome: Food Agriculture Organization of the United Nations.
2. Agricultural Statistics at a Glance, 2023. https://desagri.gov.in/wp-content/uploads/2025/01/95-2023_Agricultural-Statistics-at-a-Glance-2023.pdf
3. Kundu R, Mondal M, Garai S, Mondal R, Poddar R. Bio-efficacy of post emergence herbicides in boro rice nursery as well as main field and their residual effects on non-target microorganisms. Oryza. 2020;57(3):199-210. https://doi.org/10.35709/ory.2020.57.3.4
4. Deep M, Kumar RM, Saha S, Singh A. Rice-based cropping systems. Indian Farm. 2018 ;68(01):27-30.
5. Patra AK, Garnayak LM, Mishra KN, Mohanty TR, Mohapatra BK, Swain SK. Balanced fertilization in rice (*Oryza sativa*) groundnut (*Arachis hypogaea*) cropping system. Indian J Agron. 2019;64 (3):293-97. https://doi.org/10.59797/ija.v64i3.5272
6. Biswas P, Ghosh M, Pal S, Bandopadhyay PK, Saha A. Effect of organic and inorganic nutrient sources on growth, yield and economics of aromatic rice (*Oryza sativa*) in Gangetic delta of West Bengal. Indian J Agrono. 2023;68(1):93-6. https://doi.org/10.59797/ija.v68i1.210
7. Salma D, Venkaiah K, Naidu MV. Impact on soil properties and yield of rainfed groundnut mono cropping system (*Arachis hypogaea* L.) under long term application of manure and fertilizers. Int J Curr Microbiol. 2018;7(12):1346-60. https://doi.org/10.20546/ijcmas.2018.712.164
8. Jat AL, Srivastava VK, Chongtham SK, Singh RK. Integrated nitrogen management influences the yield performance of rice under different methods of cultivation. IJBSM. 2020;11(5):472-81. https://doi.org/10.23910/1.2020.2152
9. Baishya LK, Rathore SS, Singh D, Sarkar D and Deka BC. Effect of integrated nutrient management on rice productivity, profitability and soil fertility. Ann Plant Soil Res. 2015;17(1):86-90.
10. Lin D, Xing B. Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. Environ pollut. 2007;150(2):243-50. https://doi.org/10.1016/j.envpol.2007.01.016
11. Singh GP, Singh PL, Panwar AS. Response of groundnut (*Arachis hypogaea*) to biofertilizer, organic and inorganic sources of nutrient in north east India. Legume Res. 2011;34(3):196-201.
12. Jana K, Mondal R, Mallick GK. Growth, productivity and nutrient uptake of aerobic rice (*Oryza sativa* L.) as influenced by different nutrient management practices. Oryza. 2020;57(1):49-56. https://doi.org/10.35709/ory.2020.57.1.6
13. Sengupta A, Gunri SK, Basu TK. Performance of short duration groundnut (*Arachis hypogaea* L.) variety (TG 51) as influenced by nutrient management strategy under new alluvial zone of West Bengal. Legume Res. 2016;39(1):91-5. https://doi.org/10.18805/lr.v39i1.8869
14. Bekele G, Dechassa N, Tana T, Sharma JJ. Effects of nitrogen, phosphorus and vermicompost on groundnut yield in Babile District, eastern Ethiopia. Agron Res. 2019;17(4):1532-46. https://doi.org/10.3969/j.issn.2096-2428.2019.02.002
15. DeRosa MC, Monreal C, Schnitzer M, Walsh R, Sultan Y. Nanotechnology in fertilizers. Nat Nanotechnol. 2010;5(2):91. https://doi.org/10.1038/nnano.2010.2
16. Hassan RK, Lehmood AM. Effect of spraying time and concentration of liquid fertilizer on the growth and yield of broad bean (*Vicia faba* L.). Res crops. 2019;20(3):501-06. https://doi.org/10.31830/2348-7542.2019.072
17. Liu R, Lal R. Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (*Glycine max*). Sci Rep. 2014;4(1):5686. https://doi.org/10.1038/srep05686
18. Tanwar SP, Sharma GL, Chahar MS. Effect of phosphorus and biofertilizers on yield, nutrient content and uptake by black gram [*Vigna mungo* L.]. Legume Res. 2003;26(1):39-41.
19. Das Mohapatra M, Sahoo RK, Tuteja N. Phosphate solubilizing bacteria, Pseudomonas aeruginosa, improve the growth and yield of groundnut (*Arachis hypogaea* L.). Physiol Mol BiolPlants. 2024;30(7):1099-11. https://doi.org/10.1007/s12298-024-01478-x

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.