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Assessing the Effects of Integrated Nutrient Management on Groundnut Root Growth and Post-Harvest Soil Properties in Brown Forest Soil of South Odisha

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Abstract: The globe faces food security difficulties because of population increase and resource degradation, both worsened by climate change. Applying chemical fertilizer along with cereal-based cropping systems degrades soil health with respect to physical, chemical, and biological properties, which also results in low crop land productivity. However, adopting legume-based cropping systems with integrated nutrient management provides an appropriate way to reach Sustainable Development Goals (SDGs). Hence, a field trial was conducted on groundnut in 2018 and 2019 at the Post Graduate Research Farm, M.S. Swaminathan School of Agriculture, Paralakhemundi, Odisha, India. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with two factors as seed inoculation (solid carrier-based *Rhizobium* (SR) and liquid carrier-based *Rhizobium* (LR)) and nutrient management (N_1: 100% N (fertilizer), N_2: 75%N (fertilizer) + 25% N (FYM), N_3: 50%N (fertilizer) + 50% N (FYM), N_4: 25% N (fertilizer) + 75% N (FYM) and N_5: 100% N (through farmyard manure, FYM) in ten treatment combinations and replicated thrice. The result revealed that seed inoculation with SR and LR showed an almost similar trend in root length, dry weight and nodule, post-harvest soil pH, organic carbon and *Rhizobium* population in the soil in both years, which remained statistically at par. However, SR showed the highest value for root growth. Among nutrient management, 100% N (through inorganic fertilizer) recorded the highest root length (11.72, 19.75 and 23.9 cm) and dry weight (0.394, 1.075 and 1.141 cm) at 30, 60 and 90 days after sowing (DAS) respectively. Further, in the pooled data, the interaction effect of seed inoculation and nutrient management significantly impacted both root length and root dry weight. The nutrient management treatment and interaction effect of both factors, seed inoculation and nutrient management, significantly influenced soil organic carbon % and *Rhizobium* population. The highest and equal value of organic carbon in the soil (0.46%) was recorded from NM_3, NM_4 and NM_5 and the highest *Rhizobium* population (64.5 x 10^6 CFU g^{-1} soil) from 100% N (FYM). The results concluded that integrated nutrient management positively impacted groundnut root growth and post-harvest soil properties. The results concluded that integrated nutrient management positively impacted groundnut root growth and post-harvest soil properties. Integration of *Rhizobium* as seed inoculation, fertilizer, and organic manure (FYM) influenced soil properties and root growth, enhancing crop productivity.

Introduction

The globe faces enormous problems in guaranteeing food security, fuelled by a fast-rising population and severe soil health deterioration that has been worsened by climate change (Hossain et al., 2021; Bhadra et al., 2022; Gaikwad et al., 2022; Santosh et al., 2022; Maitra et al., 2023a). The fossil fuel-based Green Revolutions

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provided short-term food security. However, they also conditioned farmers to use excessive fertilizer, resulting in environmental degradation, lower productivity, loss of beneficial microbial diversity, soil nutrient imbalances, and so on (Ray et al., 2024; Sairam et al., 2020; Maitra and Ray, 2019; Maitra et al., 2000, 2021) Farmers in India rely on nitrogen-based fertilizers, which are frequently given through blanket prescriptions, resulting in over- or under-fertilization especially for cereal-based cropping system (Sairam et al., 2024a; Sairam et al., 2024b; Mukesh et al., 2024). Adopting a legumes-based cropping system and integrated nutrient management can be a better choice to mitigate such a scenario.

Legumes, particularly groundnut (*Arachis hypogaea* L.), provide a solution by increasing soil fertility through nitrogen fixation, encouraging beneficial microbes, improving soil health, providing climate resilience, and promoting crop diversification and crop rotation while providing economic benefits. Legumes improve soil fertility through biological nitrogen fixation (BNF), a symbiotic process that involves legume roots and *Rhizobium* bacteria (Palai et al., 2021; Mirriam et al., 2022; Maitra et al., 2023b). This relationship transforms atmospheric nitrogen into a usable form in root nodules, meeting the nitrogen requirements of the legume. Furthermore, extra nitrogen is retained in the soil, which benefits succeeding crops (Hossain et al., 2022; Jena et al., 2022). Effective nodulation is critical for improving groundnut nitrogen-fixing capability.

Groundnut is a popular oilseed crop in India. It has an area, production and productivity of 5.7 million hectares, 10.13 million tonnes and 1776 kg ha^{-1}, respectively (FAOSTAT, 2024). However, in Odisha groundnut is cultivated in an area of 204.82 thousand hectares, with a production and productivity of 387.89 thousand tonnes and 1894 kg ha^{-1}, respectively (Decades of Odisha Agriculture Statistics, 2020). The lower productivity of groundnut in Odisha is mainly due to soil fertility constraints, which are escalated by the changing climatic scenario. Excessive dependence on chemical fertilizers jeopardizes soil health, agroecosystem balance, and environmental sustainability, even though there are other ways to achieve high crop yields sustainably (Ye et al., 2020). Chemical fertilizers have limitations, such as reduced nutrient recovery, higher cultivation expenses, and the inability to deliver all needed nutrients for plant development (Babcock-Jackson et al., 2023; Shanmugavel et al., 2023). Organic manures, on the other hand, take a holistic approach, supplying a variety of nutrients while also improving soil environmental conditions (Maitra and Gitari, 2020; Sande et al., 2024) and crop quality and agricultural sustainability. Organic inputs such as FYM increase microbial activity and nutrient availability on a long-term basis, whereas biofertilizers such as *Rhizobium* improve nitrogen fixation and absorption by plants (Kumar et al., 2021; Just et al., 2024; Kumari et al., 2024). Continuous application of organic manure improves soil physicochemical properties, microbiological activities, and essential plant nutrient availability, promoting sustainable agriculture, mitigating environmental degradation, and ensuring long-term ecosystem health (Al-Shammary et al., 2024; Zheng et al., 2024). Moreover, it is aligning with "United Nation's Sustainable Development Goals like SDG 1: No Poverty, SDG 2: Zero Hunger, SDG 6: Clean Water and Sanitation, SDG 8: Decent Work and Economic Growth, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action and SDG 15: Life on Land (UN, 2024)".

Groundnut is a popular crop in south Odisha after rice, maize, green gram, black gram and mustard. As it is a leguminous oil seed crop, seed inoculation with *Rhizobium* was done to know its impact on root growth and development. In this region, groundnuts are mainly cultivated with the application of chemical fertilizer only, and there is no evidence of seed inoculation and integration of chemical fertilizer and organic manure on groundnut productivity. This study investigates the integration of organic and inorganic fertilizer along with Rhizobium-based biofertilizer in groundnut production while examining their impact on soil properties and root parameters.

Materials and methods

The field experiment was carried out in the brown forest soil of Gajapati at the Post Graduate Research Farm, M.S. Swaminathan School of Agriculture, Paralakhemundi, Odisha, India. During the crop season, the mean maximum temperature ranged from 30.1 to 34.6°C and 29.86 to 35.14°C in 2018, while the average minimum temperature ranged between 24.9 to 27.1°C and 24 to 27°C in 2019 (Figure 1). The mean relative humidity fluctuated between 76.6 to 94.5% and 57 to 86.71% in 2018 and 2019 respectively. The crop received 900.7 and 789.2 mm of cumulative rainfall during the growing period, and the average number of bright sunny hours per day was 4.32 and 5.42 respectively during both years. The soil's physicochemical parameters were determined, revealing the pH of 6.62 and an organic carbon content of 0.68%. The soil also had 263 kg ha^{-1} of available nitrogen, 12.9 kg ha^{-1} of available phosphorus, and 122.4 kg ha^{-1} of available potassium. The Factorial Randomized Block Design (FRBD) was adopted with two factors, seed inoculation and nutrition management, in ten treatment combinations that replicated thrice. The first factor was two levels of seed inoculation i.e., solid carrier-based *Rhizobium* (SR) and liquid carrier-based *Rhizobium* (LR). The second factor, nutrient management, was of five levels such as N_1: 100% N (fertilizer), N_2: 75% N (fertilizer) + 25% N (FYM), N_3: 50% N (fertilizer) + 50% N (FYM), N_4: 25% N (fertilizer) + 75% N (FYM) and N_5: 100% N (FYM). Five representative plants were carefully uprooted at 30, 60, and 90 DAS to assess root growth, following thorough watering to facilitate damage-free removal of the root system. The roots were then gently washed with water to remove adhering soil and debris. Subsequently, root length was measured using a scale and expressed as mean root length in centimetres, while the number of root nodules per plant was accurately counted. Finally, the roots were oven-dried at 65°C to attain constant weight, and dry weight was measured and expressed as grams per plant, providing a comprehensive understanding of root growth at various stages.

For determining, *Rhizobium* population in soil, 1g of soil samples were collected and serially diluted. Further, it was inoculated onto yeast extract mannitol agar (YEMA) media within a laminar airflow chamber. After incubation at 27°C for 72 hours, *Rhizobium* was identified through Gram staining and microscopic examination. As *Rhizobium* is a gram-negative rod-shaped bacterium, gram staining was done using crystal violet, iodine and ethanol and its shape was observed under a microscope for morphological and biochemical identification. Then, colony counting was done using a colony counter. CFUs may consist of pairs, chains, clusters, and single cells and are often expressed as colony-forming units per millilitre (CFU ml^{-1}).

$$\text{CFU ml}^{-1} = \frac{\text{Number of colonies} \times \text{reciprocal of dilution factor}}{\text{Volume of culture plate or the inoculums}}$$

The soil organic carbon percentage was analyzed by reacting 1g air-dried soil with $K_2Cr_2O_7$ and H_2SO_4, followed by titration with ferrous ammonium sulfate and comparison to a blank titration. The formula used for

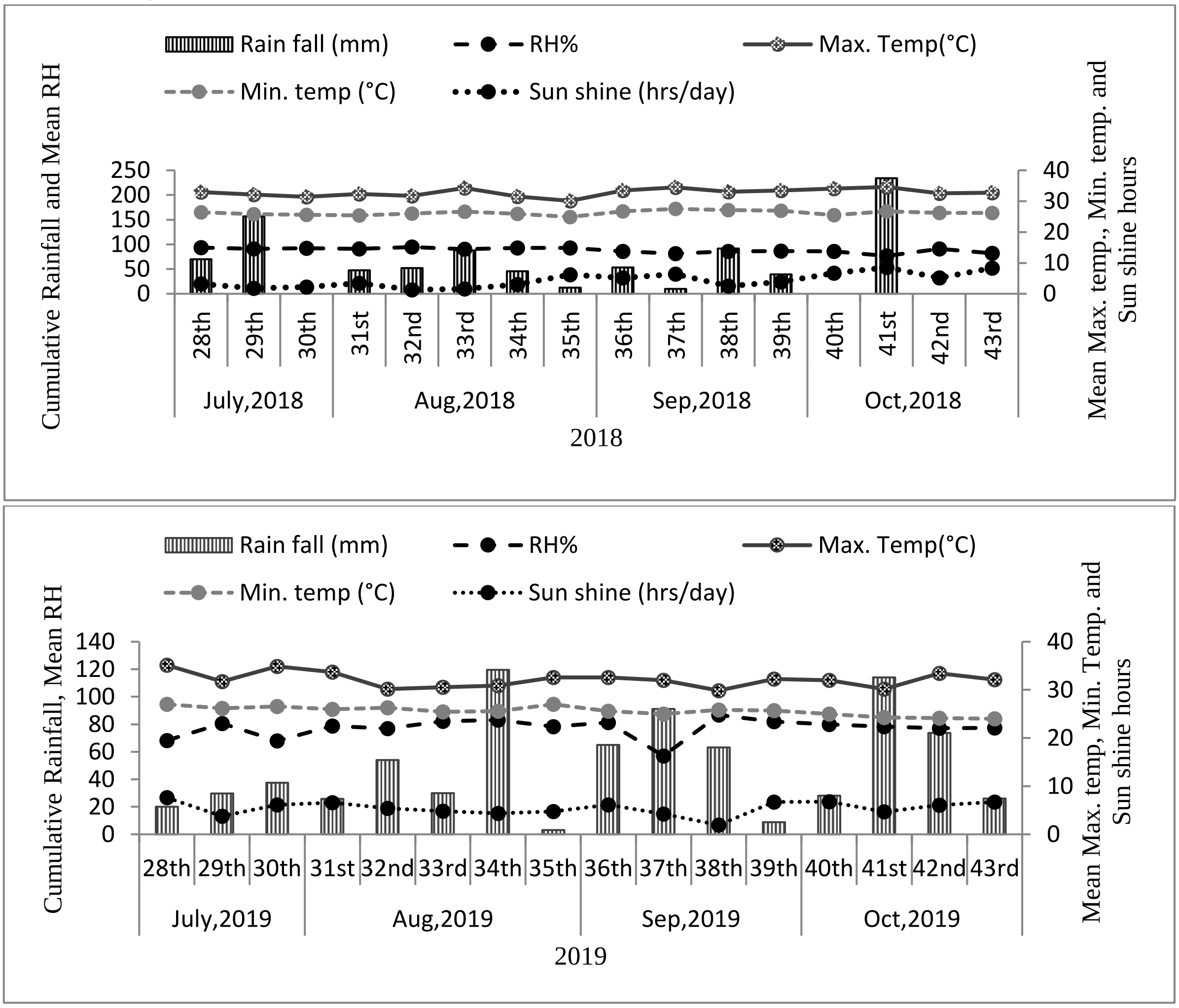
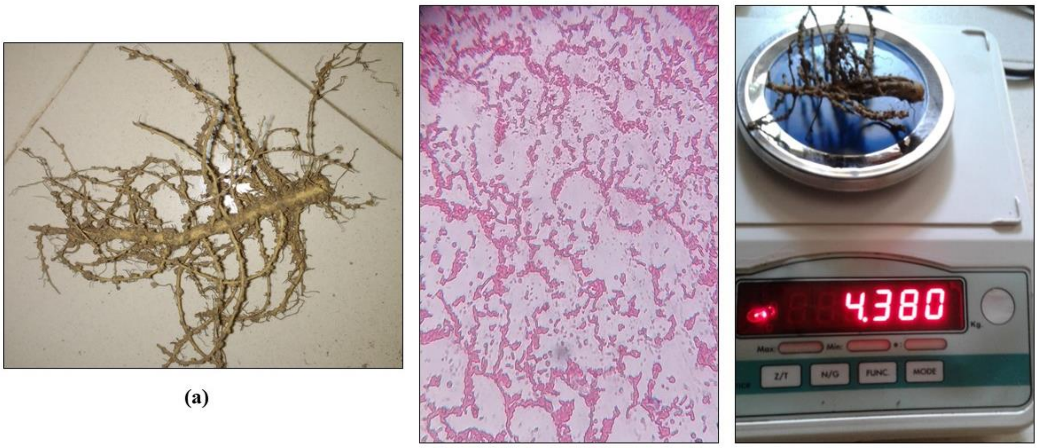


Figure 1. Weather parameters during the crop growth period in 2018 and 2019.

organic carbon calculation was as follows.

$$\text{Organic Carbon (\%)} = \frac{(\text{Volume of titrant used for blank (ml)} - \text{Volume of titrant used for sample (ml)}) \times (\text{Normality of ferrous ammonium sulfate solution} \times 3 \times 0.003)}{(\text{Weight of soil sample (g)} \times 100)}$$

Root length, root dry weight, nodules were measured from the plant samples, and *Rhizobium* population and pH and organic carbon in the post-harvest soil were tested in the laboratory (Figure 2).



(a) (b) (c)

Figure 2(a) Root nodules count, (b) *Rhizobium* population (Magnification of the image=100x) and (c) root dry weight measurement.

Data collected during the experiment were analyzed statistically using ANOVA (S.Em. ±) and critical difference (CD) at 5% significant level (Gomez and Gomez, 1984). Further, the Excel software (Microsoft Office Home and Student version 2021-en-us, Microsoft Inc., Redmond, Washington, USA) was used for statistical analysis.

Result and Discussion

Root length

Root length of groundnut at 30, 60 and 90 DAS has been recorded and presented in Table 1. As per the data recorded, there was non-significant impact between levels of seed inoculation at 30, 60 and 90 DAS in 2018, 2019, and at 60 and 90 DAS in pooled data. There was significant difference between seed inoculation with solid and liquid carrier-based *Rhizobium* at 30 DAS in pooled data. Nutrient management did not differ in the root length of groundnut at 30 DAS in 2018. In 2019, except N_5 (recorded the lowest value, i.e., 10.00 cm), others remained statistically at par with the highest root length (11.84 cm) obtained with N_1. Like 2018, a similar trend was recorded in the pooled data. The highest root length of 11.72 cm was recorded with N_1 and the lowest of 10.06 cm in N_5 as also in the pooled data. At 60 DAS in 2018, the treatment consisting of 100% RDN through inorganic fertilizer (N_1) showed the highest root length (19.8 cm), which was significantly higher than other nutrient levels that were statistically at par with each other. In 2019, the treatment N_1 showed the highest root length (19.71 cm), however, it was statistically at par with N_2. Further, it was recorded that N_4 and N_5 remained statistically at par with each other in 2019. In the pooled data, root length showed a similar trend to that recorded in 2018. The highest root length of 19.75 cm was with N_1 which was 9.46% higher than N_2. With the increase in crop age, groundnut root length (cm) increased. At 90 DAS, the effect of nutrient levels on root length showed a similar trend in both years and in the pooled data. In the pooled data, the highest root length (23.9 cm) was noted with N_1, which remained statistically at par with N_2, N_3, N_4 and significantly lowest root length (20.2cm) was registered by N_5. In pooled data on the interaction effect of two factors on groundnut root length (cm) showed a significant difference among treatment combinations at 30, 60 and 90 DAS (Figure 3). The highest root length was registered with S_1N_1 (the combination of solid carrier-based *Rhizobium* and 100% N through chemical fertilizer) and the values were 12.02 cm, 20.26 cm and 25.14 cm at 30, 60 and 90 DAS, respectively; whereas, the lowest values in terms of root length recorded were 9.83 cm with S_2N_5 at 30 DAS, 15.53 cm with S_1N_5 at 60 DAS and 19.95 cm with S_1N_5 90 DAS. These findings are in conformity with the study of Baishya et al. (2014) and Mondal et al. (2020) who recorded the superiority of 100% N application through chemical fertilizer in increasing root length of groundnut.

Root dry weight

There was no significant difference between solid and liquid carrier-based *Rhizobium* seed inoculation on root dry weight (g) plant^{-1} in both years of experimentation as well as in pooled data (Table 2). At 30 DAS, there was non-significant difference among different levels of nutrients on root dry weight (g) plant^{-1} in 2018. In 2019, the highest root dry weight (0.403 g) was recorded in N_1, which was statistically comparable with N_2 and remained significantly higher than N_3, N_4 and N_5. The treatment comprised of 100% RDN through inorganic fertilizer (N_1) recorded 8.93 % higher root dry weight than N_3 in the production of root dry weight (g) plant^{-1}. In the pooled data, N_1 showed the highest root dry weight (0.394 g), which was statistically at par with N_2, N_3 and N_4. However, the lowest root dry weight plant^{-1} (0.324 g) was observed in N_5:100% RDN (FYM).

dry weight plant^{-1} (1.02 g) which was statistically comparable with N_2 and N_3. Further, the lowest root dry weight plant^{-1} (0.731 g) was recorded with N_5, which was at par with N_4. The treatment N_1 recorded 16.37% higher than N_4 in root dry weight plant^{-1} expression. In 2019, the highest root dry weight plant^{-1} (1.13 g) was recorded in N_1 and was significantly higher than the remaining nutrient levels. The treatment with 100% RDN through inorganic fertilizer (N_1) produced 12.3% higher root dry weight than N_2. In the pooled data, N_1 showed its superiority in the expression of root dry-weight plant^{-1} (1.075 g) to other nutrient levels, but remained statistically at par with N_2. The treatment N_1, resulted in 18.32 % more root dry weight plant^{-1} than N_3. As noted in

Table 1. Effect of seed inoculation and nutrient levels on root length (cm) of groundnut.

	2018			2019			Pooled		
Treatment	**30 DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
Seed inoculation									
S_1	11.20	17.17	21.98	11.38	17.95	23.21	11.29	17.56	22.59
S_2	10.57	16.73	21.44	10.76	17.81	22.82	10.67	17.27	22.13
S.Em. ±	0.28	0.53	0.60	0.25	0.31	0.52	0.27	0.48	0.65
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.77	NS	NS
Nutrient levels									
N_1	11.60	19.80	23.17	11.84	19.71	24.63	11.72	19.75	23.90
N_2	11.24	17.27	23.00	11.47	18.50	23.86	11.35	17.88	23.43
N_3	10.93	16.02	22.28	11.30	17.78	22.53	11.12	16.90	22.41
N_4	10.55	15.97	21.28	10.76	17.16	22.46	10.65	16.56	21.87
N_5	10.13	15.72	18.82	10.00	16.24	21.58	10.06	15.98	20.20
S.Em. ±	0.44	0.84	0.96	0.39	0.49	0.83	0.42	0.76	1.03
CD (P=0.05)	NS	2.48	2.84	1.16	1.44	2.46	1.21	2.17	2.96
S x N	NS	NS	NS	NS	NS	NS	S	S	S

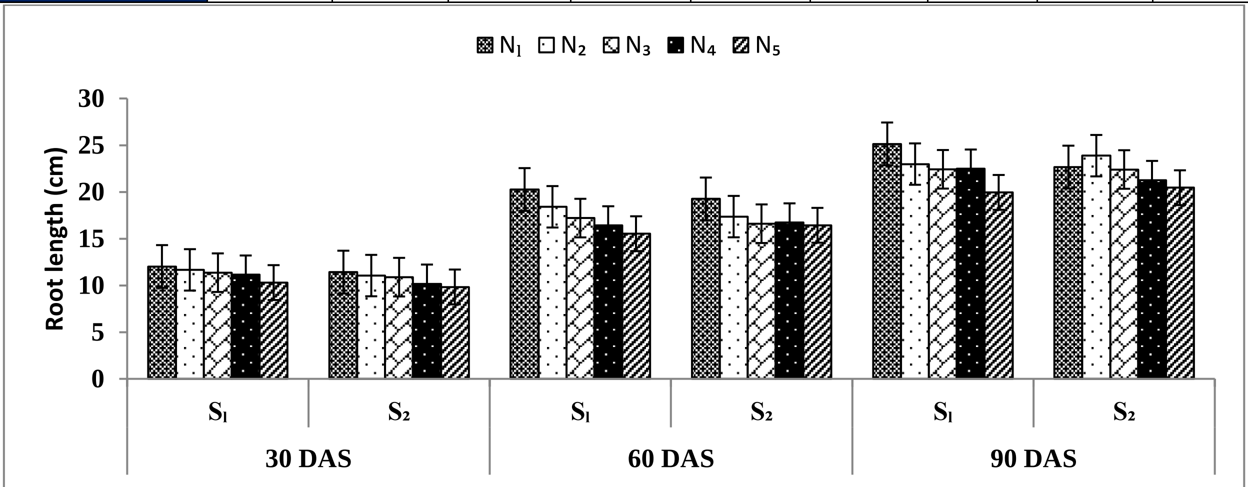


Figure 3. Interaction effect of seed inoculation and nutrient management on root length of groundnut (based on the pooled data of two years) S_1, solid carrier-based Rhizobium; S_2, liquid carrier-based Rhizobium; N_1 to N_5, levels of nutrients.

There was a significant difference between different levels of nutrient management on root dry weight plant^{-1} at 60 DAS. In 2018, treatment N_1 recorded highest root earlier cases, the treatment N_5 recorded the lowest root dry weight plant^{-1} (0.781 g) at the same growth stage. The effect of different levels of nutrient management on root

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dry weight plant^{-1} showed a similar trend at 90 DAS in both the years and in the pooled data. N_1 registered the highest root dry weight plant^{-1} (1.141 g), which was significantly higher than remaining nutrient levels and it was 15.24% higher than N_2. The lowest root dry weight (0.822 g) was recorded in N_5 where compost was applied to supply nutrients.

The interaction effect between two factors on root dry weight plant^{-1} showed a significant difference, as shown by the treatment combinations (Figure 4). At 30 DAS, the treatment S_1N_1 recorded the highest root dry weight plant^{-1} (0.408 g) and it was statistically at par with all the treatment combinations except S_1N_4, S_1N_5 and S_2N_5. At 60 DAS, the treatment combination S_2N_1 recorded the highest root dry weight plant^{-1} (1.079 g) and it remained statistically at par with other treatment combinations, except S_1N_4, S_1N_5, S_2N_4 and S_2N_5. At 90 DAS, though S_1N_1 registered the highest root dry weight plant^{-1} (1.2 g), it was at par with S_2N_1 and significantly higher than other treatment combinations. This could be due to a greater and fast mineralization of nitrogen from inorganic fertilizer, which helped achieve better groundnut root development. The results corroborate findings of Mohammad and Alobaidy (2023) and Kumar et al. (2021) who recorded similar findings in groundnut and rice respectively.

Table 2. Effect of seed inoculation and nutrient management on groundnut root dry weight (g) per plant.

Treatments	2018			2019			Pooled		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Seed inoculation									
S_1	0.345	0.899	0.961	0.366	0.931	0.969	0.355	0.915	0.965
S_2	0.375	0.882	0.911	0.363	0.903	0.981	0.369	0.892	0.946
S.Em. ±	0.011	0.035	0.021	0.007	0.025	0.027	0.010	0.034	0.027
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels									
N_1	0.385	1.020	1.095	0.403	1.130	1.188	0.394	1.075	1.141
N_2	0.377	0.933	0.944	0.380	0.953	0.991	0.379	0.943	0.967
N_3	0.358	0.917	0.926	0.367	0.838	0.940	0.363	0.878	0.933
N_4	0.353	0.853	0.918	0.352	0.832	0.910	0.353	0.842	0.914
N_5	0.327	0.731	0.797	0.321	0.831	0.848	0.324	0.781	0.822
S.Em. ±	0.018	0.055	0.034	0.011	0.039	0.043	0.016	0.054	0.043
CD (P=0.05)	NS	0.165	0.101	0.032	0.116	0.129	0.046	0.156	0.124
S x N	NS	NS	NS	NS	NS	NS	S	S	S

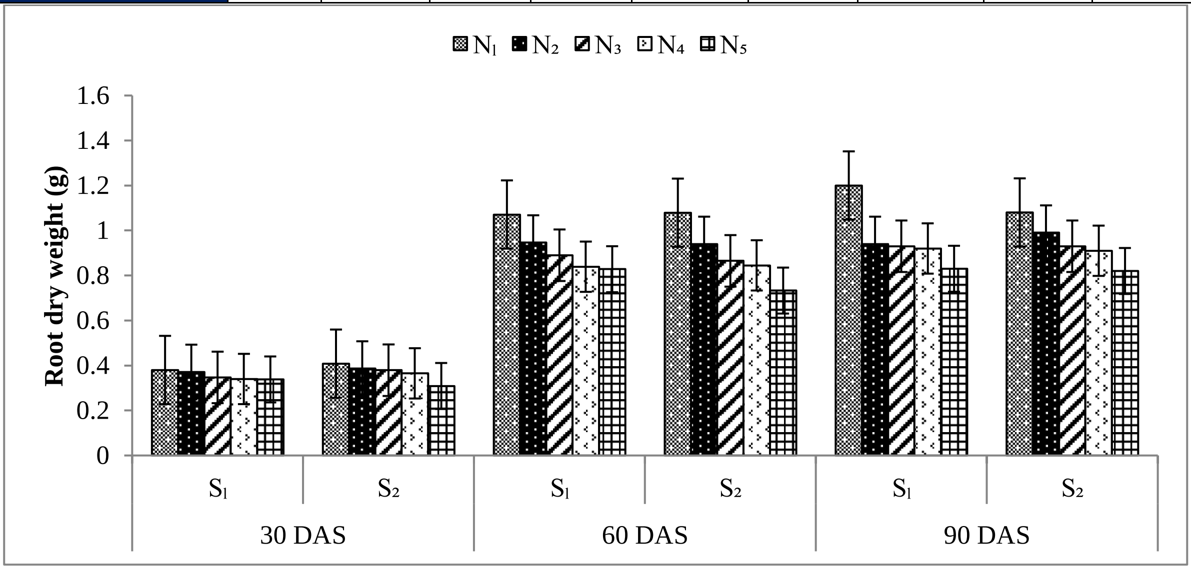

Figure 4. Interaction effect of seed inoculation and nutrient levels on root dry weight of groundnut (pooled data of two years) S_1, solid carrier-based *Rhizobium*; S_2, liquid carrier-based *Rhizobium*; N_1 to N_5, levels of nutrients.

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Number of root nodules per plant

Effect of seed inoculation and nutrient management on number of rot nodule plant^{-1} of groundnut showed that there was non-significant difference between *Rhizobium* seed inoculation treatments on number of root nodules plant^{-1}at 30 DAS and 90 DAS in both the years and pooled data (Table 3). At 60 DAS, there was significant difference between the two levels of seed inoculation in 2019 and pooled data. The treatment comprising of liquid carrier-based *Rhizobium* seed inoculation (S_2) recorded higher number of root nodules plant^{-1} of 8.22 and 8.99 in 2019 and pooled data, respectively than solid carrier-based *Rhizobium* seed inoculation (S_1). Similar findings were obtained earlier by Kumawat et al. (2017).

At 30 DAS, there was non-significant difference between different levels of nutrient management in 2018 and 2019. However, the pooled data showed that the highest number (82.3) of root nodules plant^{-1} was recorded in N_5 and lowest (70.57) in N_1: 100% RDN. At 60 DAS, number of root nodules plant^{-1} was peak among all growth stages and showed similar trend with different levels of nutrient management in 2018, 2019 and pooled data. As noted at the earlier growth stage, at 60 DAS, the treatment N5 also recorded the highest (156.99) number of root nodule plant^{-1}, but it was statistically at par with N_3 and N_4. The treatment N_5 recorded a significantly

Table 3. Effect of seed inoculation and nutrient management on number of root nodule per plant of groundnut.

Treatments	2018			2019			Pooled		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Seed inoculation									
S_1	73.99	135.38	124.23	81.97	145.83	128.77	77.98	140.61	126.50
S_2	71.51	136.56	123.35	80.46	160.43	126.91	75.99	148.50	125.13
S.Em. ±	2.18	2.60	2.14	2.51	2.77	2.03	2.79	3.10	2.37
CD (P=0.05)	NS	NS	NS	NS	8.22	NS	NS	8.99	NS
Nutrient levels									
N_1	66.37	118.73	108.07	74.77	142.33	118.58	70.57	130.53	113.33
N_2	70.73	127.97	116.75	80.00	149.75	121.25	75.36	138.86	119.00
N_3	72.47	139.34	122.03	81.23	157.25	122.50	76.85	148.30	122.27
N_4	75.30	143.23	131.92	84.35	152.92	133.58	79.83	148.08	132.75
N_5	78.87	150.57	140.18	85.73	163.42	143.27	82.30	156.99	141.73
S.Em. ±	3.45	4.11	3.38	3.97	4.37	3.21	4.41	4.90	3.74
CD (P=0.05)	NS	12.20	10.04	NS	12.99	9.53	NS	14.21	10.73
SI x NS	NS	NS	NS	NS	NS	NS	NS	NS	S

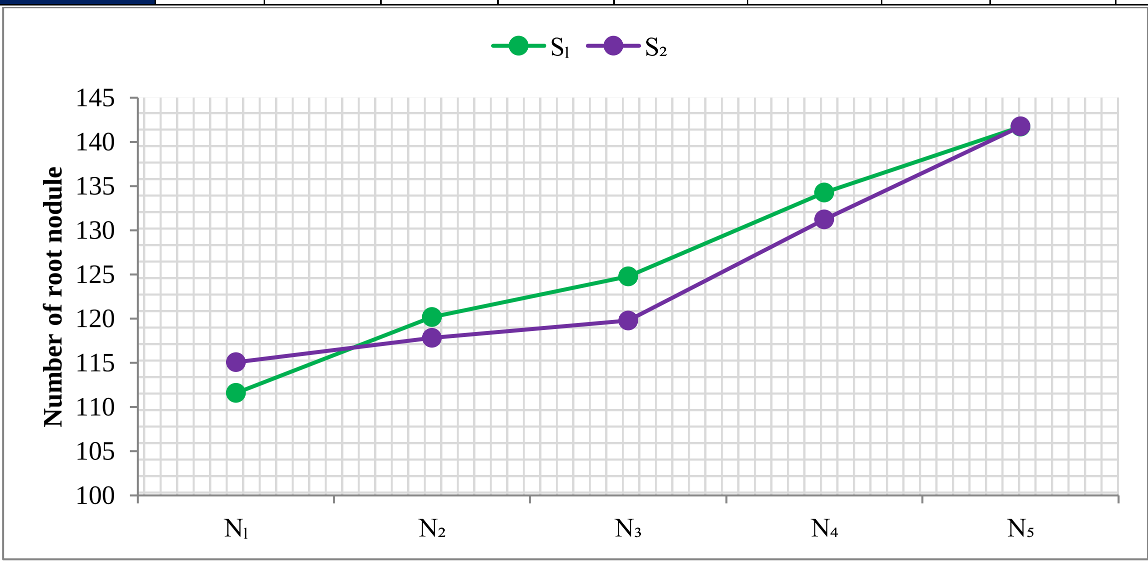

Figure 5. Interaction effect of seed inoculation and nutrient levels on number of root nodule of groundnut at 90 DAS (pooled data of two years) S_1, solid carrier-based *Rhizobium*; S_2, liquid carrier-based *Rhizobium*; N_1 to N_5, levels of nutrients.

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higher number of root nodules plant^{-1} than N_1 and N_2. However, N_1 and N_2 were at par with each other, and N1 resulted in the lowest (130.53) number of root nodules in plant^{-1}. Number of root nodules plant^{-1} was decreased towards maturity because of denaturation. The pooled data revealed that the number of root nodules plant^{-1} at 90 DAS was highest (141.73) with the treatment N_5 which was also statistically at par with N_4. However, the lowest (113.33) number of root nodules plant $^{-1}$ was recorded in N_1, which was statistically at par with N_2 and N_3.

Interaction effect of seed inoculation and nutrient management on number of root nodules plant^{-1} showed a significant difference among the treatment combinations at 90 DAS (Figure 5). The treatment combination comprising of S_2N_5 recorded highest (141.75) number of root nodules plant^{-1}, which was at par with S_1N_5, S_1N_4 and S_2N_4. Similar results were observed by Prajapat et al. (2015) where they recorded that lower level of inorganic fertilizer nitrogen along with organic manure and biofertilizer application boosted root nodules probably because of the congenial environment in the rhizosphere and higher *Rhizobium* population.

The total number of root nodules in plant-1 was higher for the level with 100% RDN (FYM) and lowest in the level with 100% RDN (inorganic fertilizer). This might be due to the supply of higher soil available nitrogen reduced efficiency of symbiosis between legume and *Rhizobium*. Similar findings were also recorded by Baishya et al. (2014) and Bekele (2022).

Soil organic carbon %, pH and *Rhizobium* population

The effect of seed inoculation with solid and liquid carrier-based *Rhizobium* on OC %, pH, and Rhizobium population did not show any significant variation in either 2018 or 2019, nor did the pooled data (Table 4). However, the highest organic carbon in soil (0.46 %) and soil pH (6.43) were recorded from liquid carries-based inoculation, however, the highest *Rhizobium* population (54.37 x 10^6 CFU g^{-1} soil) was found in solid carrier-based inoculation treatment, though the difference was non-significant. However, there was a significant difference between nutrient levels in terms of organic carbon content and *Rhizobium* population dynamics. As per 2018 data, the treatments N_5, N_4 and N_3 were statistically at par with each other and N_5 recorded the highest (0.46%) soil organic carbon. The treatment N_1 recorded the lowest value (0.42%) in organic carbon content and was significantly lower than other treatments studied. In 2019, there was non-significant difference among the nutrient management treatments on organic carbon content. In pooled data, the treatments N_5, N_4 and N_3 recorded on-par values of organic carbon content and they were also statistically at par with the treatment N_2, but significantly higher than N_1. However, the pooled data resulted in a significant variation among treatment combinations, as recorded in as the interaction effect. The highest organic carbon (0.47 %) was noted in S_2N_4 and S_2N_5, and the treatment combinations were statistically on par with all treatment combinations except S_1N_1. Organic carbon % in the post-harvest soil might be increased due to the addition of organic matter as FYM. The effect of different levels of nutrient management on soil pH did not show any significant difference in the year 2018 and 2019. However, the pooled data showed significant differences among nutrient levels. The treatment N_2 recorded the highest value (6.55) soil pH and it remained statistically at par with N_1, N_3 and N_4 but significantly higher than N_5. Moreover, the treatment combination S_2N_2 registered the highest soil pH (6.66) and was statistically at par with all treatment combinations except S_2N_3, S_1N_4 and S_1N_5 (Figure 6). In 2018, the treatment N_5 resulted in highest *Rhizobium* population (62.17 x 10^6 CFU g^{-1} soil) in the post-harvest soil which was statistically at par with N_4; but significantly higher than N_3, N_2 and N_1. The treatment N_4 was also significantly superior to N_3, N_2 and N_1. The treatment N_1 recorded the lowest *Rhizobium* population (39.17 x 10^6 CFU g^{-1} soil) in post-harvest soil and it was significantly lower than all. In 2019, the treatment N_5 recorded the maximum *Rhizobium* population (66.83 x 10^6 CFU g^{-1} soil) in the post-harvest soil and it was significantly higher than N_4, N_3, N_2 and N_1. The treatments N_4, N_3 and N_2 were also statistically at par with each other. Though the treatment N_1 resulted in the lowest *Rhizobium* population (51 x 10^6 CFU g^{-1} soil), but it was statistically at par with N_2. The pooled data registered that the treatment N_5 resulted in the highest *Rhizobium* population (64.5 x 10^6 CFU g^{-1} soil) and significantly higher than the remaining four levels of nutrient levels. The treatment N_3 recorded a lower value than N_4 and a higher value than N_2 but remained on par with N_4 and N_2. The treatment N_1 recorded the lowest *Rhizobium* population (45.08 x 10^6 CFU g^{-1} soil) in the post-harvest soil and it was significantly lower than all nutrient levels. The interaction effect of seed inoculation and nutrient management on *Rhizobium* population showed significant differences among treatment combinations. The treatment combination S_1N_5 recorded maximum *Rhizobium* population (64.83 x 10^6 CFU g^{-1} soil) and was at par with S_2N_5 and S_1N_4 (Figure 6). Earlier, Irungbam et al. (2018), Tekulu et al. (2020), Pavani et al. (2021) and Sande et al. (2024). I recognized the significant role of the combination of organic manures and chemical nutrients in *Rhizobium* population and soil organic carbon enhancement of the post-harvest soil of groundnut. Soil application of FYM as organic

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manure improves organic carbon content, soil water holding capacity, soil fertility and microbial activity. Microbial activity improves with the addition of organic matter by increasing enzyme production, decomposition rate, and mineralization of nutrients (Verma et al. 2024). This might be the reason for the higher *Rhizobium* population from the treatment, which consists of 100% N through FYM.

The results revealed that seed inoculation with solid carrier-based *Rhizobium* yielded a higher value for most root parameters. Applying 100% nitrogen through inorganic fertilizer showed the highest root growth, but replacing some nitrogen with FYM improved soil organic carbon content and microbial population dynamics. However, 75% N (through inorganic fertilizer) + 25% N (FYM) showed statistically similar results. The study concludes that the farmers in South Odisha may integrate seed inoculation with solid carrier-based *Rhizobium*, 75 % nitrogen through inorganic fertilizer and 25% nitrogen through FYM, to increase crop growth of groundnut

Table 4. Effect of seed inoculation and nutrient management on soil organic carbon, pH and *Rhizobium* population in the post-harvest soil of groundnut.

Treatments	2018			2019			Pooled		
	OC %	pH	*Rhizobium* population (10^6 CFU g^{-1} soil)	OC %	pH	*Rhizobium* population (10^6 CFU g^{-1} soil)	OC %	pH	*Rhizobium* population (10^6 CFU g^{-1} soil)
Seed inoculation									
S_1	0.44	6.31	49.33	0.45	6.35	59.40	0.45	6.33	54.37
S_2	0.45	6.42	49.67	0.47	6.45	56.73	0.46	6.43	53.20
S.Em. ±	0.006	0.052	0.972	0.007	0.05	1.31	0.007	0.05	1.33
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels									
N_1	0.42	6.32	39.17	0.44	6.36	51.00	0.43	6.34	45.08
N_2	0.44	6.53	44.33	0.46	6.57	55.83	0.45	6.55	50.08
N_3	0.45	6.32	47.83	0.46	6.35	56.00	0.46	6.33	51.92
N_4	0.45	6.37	54.00	0.48	6.40	60.67	0.46	6.38	57.33
N_5	0.46	6.29	62.17	0.47	6.33	66.83	0.46	6.31	64.50
S.Em. ±	0.009	0.082	1.537	0.011	0.08	2.07	0.011	0.08	2.10
CD (P=0.05)	0.027	NS	4.567	NS	NS	6.14	0.032	0.24	6.10
S x N	NS	NS	NS	NS	NS	NS	S	S	S

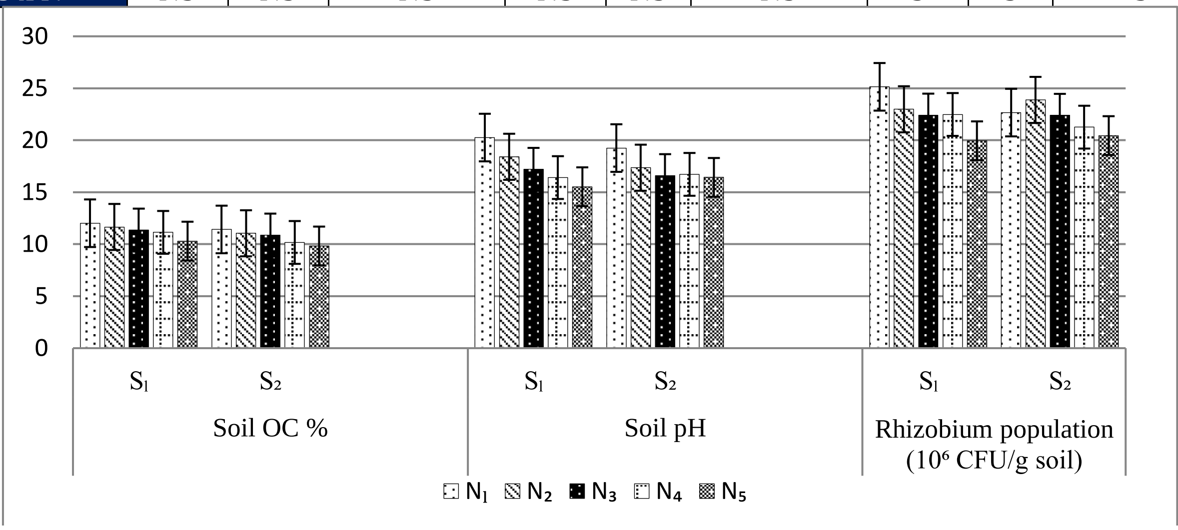

Figure 6. Interaction effect of seed inoculation and nutrient levels on soil OC%, soil pH, and *Rhizobium* population on post-harvest soil of groundnut (pooled data of two years)
S_1R, solid carrier-based *Rhizobium*; S_2, liquid carrier-based *Rhizobium*; N_1 to N_5, levels of nutrients.

Conclusion

In the current study, integrated nutrient management using *Rhizobium* inoculation with inorganic fertilizer and organic manures improved soil physiochemical characteristics, microbial population, and root metrics.

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while regaining soil health. The farmer may utilize the residual soil fertility for the cultivation of second crop with less fertilizer input, as the leguminous groundnut, seed inoculation with Rhizobium and integration of inorganic fertilizer and organic manure application influenced the post-harvest soil. Nonetheless, further research can offer a window into some more nutrient sources and various biofertilizers based on compatibility in the region with enhanced agronomic management techniques.

Conflict of interest

All the authors involved in this manuscript preparation declare that they don't have any conflict of interest.

References

Al-Shammary, I.B.G., Al-Shihmani, L.S.S., Fernández-Gálvez, J., & Andrés Caballero-Calvo, A. (2024). Optimizing sustainable agriculture: A comprehensive review of agronomic practices and their impacts on soil attributes. *Journal of Environmental Management*, *364*, 121487. https://doi.org/10.1016/j.jenvman.2024.121487.

Babcock-Jackson, L., Konovalova, T., Krogman, J.P., Bird, R., & Díaz, L.L. (2023). Sustainable fertilizers: Publication landscape on wastes as nutrient sources, wastewater treatment processes for nutrient recovery, biorefineries, and green ammonia synthesis. *Journal of Agricultural and Food Chemistry*, *71*(22), 8265-8296. https://doi.org/10.1021/acs.jafc.3c00454.

Baishya, L.K., Ansari, M.A., Singh, R., Deka, B.C., Prakash, N., & Ngachan, S.V. (2014). Response of groundnut (*Arachis hypogaea*) cultivars to integrated nutrient management on productivity, productivity and nutrient uptake in NEH region. *Indian Journal of Agricultural Sciences*, *84*(5), 612-615. https://doi.org/10.56093/ijas.v84i5.40486

Bekele, G., Dechassa, N., & Tana, T. (2022). Effect of inorganic and organic fertilizers on productivity of groundnut (*Arachis hypogaea* L.) varieties in East Hararghe, Eastern Ethiopia. *Oil Crop Science*, *7*(3), 112-121. https://doi.org/10.1016/j.ocsci.2022.07.002.

Bhadra, P., Maitra, S., Shankar, T., Hossain, A., Praharaj, S., & Aftab, T. (2022). Climate change impact on plants: Plant responses and adaptations. In A. Roychoudhury & T. Aftab (Eds.), *Plant Perspectives to Global Climate Changes* (pp. 1-24). Academic Press.

Directorate of Agriculture and Food Production, Odisha. (2020). *Five Decades of Odisha Agriculture Statistics*. http://agriodisha.nic.in/content/pdf/Five%20Decades%20of%20Odisha%20Agriculture%20Statistics.pdf (Accessed on 22nd September 2024).

FAOSTAT. (2024). *Crop Statistics*. https://www.fao.org/faostat/en/#data/QCL (Accessed on 28th September 2024).

Gaikwad, D.J., Ubale, N.B., Pal, A., Singh, S., Ali, M.A., & Maitra, S. (2022). Abiotic stresses impact on major cereals and adaptation options – A review. *Research on Crops*, *23*(4), 896-915. https://doi.org/10.31830/2348-7542.2022.ROC-913.

Gomez, K.A., & Gomez, A.A. (1984). *Statistics Procedures for Agriculture Research*. John Wiley & Sons, USA.

Hossain, A., Maitra, S., Ahmed, S., Mitra, B., Ahmad, Z., Garai, S., Mondal, M., Adeel, M., Shankar, T., & Meena, R.S. (2022). Legumes for nutrient management in the cropping system. In R.S. Meena & S. Kumar (Eds.), *Advances in Legumes for Sustainable Intensification* (pp. 93-112). Academic Press.

Hossain, A., Pramanick, B., Bhutia, K.L., Ahmad, Z., Moulick, D., Maitra, S., Ahmad, A., & Aftab, T. (2021). Emerging roles of osmoprotectant glycine betaine against salt-induced oxidative stress in plants: A major outlook of maize (*Zea mays* L.). In T. Aftab & K.R. Hakeem (Eds.), *Frontiers in Plant-Soil Interaction: Molecular Insights into Plant Adaptation* (pp. 567-587). Academic Press.

Irungbam, P., Pramanick, M., Lepcha, R., & Sanatombi, Y. (2018). Productivity of summer groundnut (*Arachis hypogaea* L.) and soil properties as influenced by different nutrient management in new alluvial zone of West Bengal. *The Bioscan*, *13*(1), 261-265.

Jena, J., Maitra, S., Hossain, A., Pramanick, B., Gitari, H.I., Praharaj, S., Shankar, T., Palai, J.B., Rathore, A., Mandal, T.K., & Jatav, H.S. (2022). Role of legumes in cropping systems for soil ecosystem improvement. In: H.S. Jatav (Ed.), *Ecosystem Services*, pp. 1-21.

Just, B.S., Marks, E.A.N., Roquer-Beni, L., Llenas, L., Ponsà, S., & Vilaplana, R. (2024). Biofertilization increases soil organic carbon concentrations: Results of a meta-analysis. *International Journal of Agricultural Sustainability*, *22*(1). https://doi.org/10.1080/14735903.2024.2361578.

Kumar, G.S., Kumar, R.M., Sreenivas, A., Jayasree, G., & Ramesh, T. (2021). Evaluation of establishment methods and nutrient management practices on growth rate, root weight, water productivity and yield of rice. *The Pharma Innovation Journal*, 10(8), 988-994.

Kumar, S., Diksha, Sindhu, S.S., & Kumar, R. (2021). Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences*, *3*, 100094. https://doi.org/10.1016/j.crmicr.2021.100094.

Kumari, M., Sheoran, S., Prakash, D., Yadav, D.B., Yadav, P.K., Jat, M.K., Ankit, & Apurva. (2024). Long-term application of organic manures and chemical fertilizers improve the organic carbon and microbiological properties of soil under pearl millet-wheat cropping system in North-Western India. *Heliyon*, *10*(3), e25333. https://doi.org/10.1016/j.heliyon.2024.e25333.

Kumawat, K., Patel, P. P., Dambiwal, D., Reddy, T. V., Chouthu, Ram Hakla, C. P. (2017). Effect of liquid and solid bio-fertilizers (*Rhizobium* and PSB) on growth attributes, yield, and economics of fenugreek (*Trigonella foenum-graecum* L.). *International Journal of Chemical Studies*, *5*(4), 239-242.

Maitra, S., & Gitari, H.I. (2020). Scope for adoption of intercropping system in organic agriculture. *Indian Journal of Natural Science*, *11*(63), 28624-28631.

Maitra, S., & Ray, D.P. (2019). Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems: A review. *International Journal of Bioresource Science*, *6*(1), 11-19. https://doi.org/10.30954/2347-9655.01.2019.3

Maitra, S., Ghosh, D.C., Sounda, G., Jana, P.K., & Roy, D.K. (2000). Productivity, competition and economics of intercropping legumes in finger millet (*Eleusine coracana*) at different fertility levels. *Indian Journal of Agricultural Science*, *70*, 824-828.

Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H.I., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J.B., Jana, J., Bhattacharya, U., Duvvada, S.K., Lalichetti, S., & Sairam, M. (2021). Intercropping – A low input agricultural strategy for food and environmental security. *Agronomy*, *11*(2), 343. https://doi.org/10.3390/agronomy11020343.

Maitra, S., Praharaj, S., Brestic, M., Sahoo, R.K., Sagar, L., Shankar, T., Palai, J.B., Sahoo, U., Sairam, M., Pramanick, B., Nath, S., Venugopalan, V.K., Skalický, M., & Hossain, A. (2023b). Rhizobium as biotechnological tools for green solutions: An environment friendly approach for sustainable crop production in the modern era of climate change. *Current Microbiology*, *80*, 219. https://doi.org/10.1007/s00284-023-03317-w.

Maitra, S., Sahoo, U., Sairam, M., Gitari, H.I., Rezaei-Chiyaneh, E., Battaglia, M.L., & Hossain, A. (2023a). Cultivating sustainability: A comprehensive review on intercropping in a changing climate. *Research on Crops*, *24*(4), 702-715. https://doi.org/10.31830/2348-7542.2023.ROC-1020.

Mirriam, A., Mugisha, J., & Maitra, S. (2021). Yield response of groundnut varieties (*Arachis hypogaea* L.) to different organic manure amendments under humid tropical conditions. *International Journal of Agriculture and Environmental Research*, *7*(4), 578-584.

Mohammad, R. H., & Alobaidy, B. Sh. J. (2023). The effect of Rhizobia inoculum and mineral fertilizers on the number of root nodes, growth, and yield of groundnut. *IOP Conference Series: Earth and Environmental Science*, 1252, 012027. https://doi.org/10.1088/1755-1315/1252/1/012027.

Mondal, M., Skalicky, M., Garai, S., Hossain, A., Sarkar, S., Banerjee, H., Kundu, R., Brestic, M., Barutcular, C., Erman, M., Sabagh, A. E. L., & Laing, A. M. (2020). Supplementing nitrogen in combination with Rhizobium inoculation and soil mulch in peanut (*Arachis hypogaea* L.) production system: Part II. Effect on phenology, growth, yield attributes, pod quality, profitability, and nitrogen use efficiency. *Agronomy*, *10*, 1513. https://doi.org/10.3390/agronomy10101513

Mukesh, G., Sairam, M., Maitra, S., Gaikwad, D. J., Sagar, L., & Ray, S. (2024). Agrometeorological indices, physiological growth parameters and performance of finger millet as influenced by different cultivars under hot and sub-humid region of Odisha. *International Journal of Experimental Research and Review*, *42*, 148–161. https://doi.org/10.52756/ijerr.2024.v42.013.

Palai, J. B., Malik, G. C., Maitra, S., & Banerjee, M. (2021). Role of Rhizobium on growth and development of groundnut: A review. *International Journal of Agriculture Environment and Biotechnology*, *14*(1), 63–73. https://doi.org/10.30954/0974-1712.01.2021.7.

Pavani, B., Swaroop, N., David, A. A., & Barthwal, A. (2021). Effect of different levels of FYM, neem cake and Rhizobium on physico-chemical properties of soil in Prayagraj region. *The Pharma Innovation Journal*, *10*(12), 283–289.Prajapat, K., Vyas, A. K., & Dhar, S. (2015). Effect of cropping systems and nutrient management practices on growth, productivity, economics, and nutrient uptake of soybean (*Glycine max*). *Indian Journal of Agricultural Sciences*, *85*, 1138–1143. https://doi.org/10.56093/ijas.v85i9.51555

Ray, S., Maitra, S., Sairam, M., Sravya, M., Priyadarshini, A., Shubhadarshi, S., & Padhi, D. P. (2024). An unravelled potential of foliar application of micro and beneficial nutrients in cereals for ensuring food and nutritional security. *International Journal of Experimental Research and Review*, *41*(Spl Vol), 19–42. https://doi.org/10.52756/ijerr.2024.v41spl.003.

Sairam, M., Maitra, S., Sain, S., Gaikwad, D. J., & Sagar, L. (2024a). Dry matter accumulation and physiological growth parameters of maize as influenced by different nutrient management practices. *Agricultural Science Digest*, *44*(2), 219–225. https://doi.org/10.18805/ag.D-5835

Masina Sairam, Ray, S., Shankar, T., Pal, A., Priya, K.V., & Maitra, S. (2024b) Energetics and economics of *Rabi* maize as influenced by smart nutrient management under South Odisha conditions. *International Journal of Experimental Research and Review*, *44*, pp. 221–223.

Sairam, M., Shankar, T., Maitra, S., & Duvvada, S. K. (2020). Effect of integrated nutrient management on growth, yield, nutrient content, and economics of summer rice (*Oryza sativa* L.). *Indian Journal of Pure and Applied Biosciences*, *8*(3), 421–427. https://doi.org/10.18782/2582-2845.8172.

Sande, T. J., Tindwa, H. J., Alovisi, A. M. T., Shitindi, M. J., & Semoka, J. M. (2024). Enhancing sustainable crop production through integrated nutrient management: A focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilizers – A systematic review. *Frontiers in Agronomy*, *6*, 1422876. https://doi.org/10.3389/fagro.2024.1422876.

Santosh, D. T., Debnath, S., Maitra, S., Sairam, M., Sagar, L., Hossain, A., & Moulick, D. (2022). Alleviation of climate catastrophe in agriculture through adoption of climate-smart technologies. In *Climate Crisis: Adaptive Approaches and Sustainability* (pp. 307–332). Springer Nature Switzerland.

Shanmugavel, D., Rusyn, I., Solorza-Feria, O., & Kamaraj, S. (2023). Sustainable SMART fertilizers in agriculture systems: A review on fundamentals to in-field applications. *Science of The Total Environment*, *904*, 166729. https://doi.org/10.1016/j.scitotenv.2023.166729.

Tekulu, K., Taye, G., & Assefa, D. (2020). Effect of starter nitrogen and phosphorus fertilizer rates on yield and yield components, grain protein content of groundnut (*Arachis hypogaea* L.) and residual soil nitrogen content in a semiarid north Ethiopia. *Heliyon*, *6*(10), e05101. https://doi.org/10.1016/j.heliyon.2020.e05101.

UN. (2024). Sustainable development, the 17 goals. Retrieved from https://sdgs.un.org/goals (accessed 29 August 2024).

Verma, S., Pradhan, S.S., Singh, A., & Kushuwaha, M., (2024). Effect of organic manure on different soil properties: A review. *International Journal of Plant and Soil Science*, 36(5), 182-187. https://doi.org/10.9734/IJPSS/2024/v36i54515

Ye, L., Zhao, X., Bao, E., Li, J., Zou, Z., & Cao, K. (2020). Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. *Scientific Reports*, *10*, 177. https://doi.org/10.1038/s41598-019-56954-2

Zheng, X., Wei, L., Lv, W., Zhang, H., Zhang, Y., Zhang, H., Zhang, H., Zhu, Z., Ge, T., & Zhang, W. (2024). Long-term bioorganic and organic fertilization improved soil quality and multifunctionality under continuous cropping in watermelon. *Agriculture, Ecosystems & Environment*, *359*, 108721. https://doi.org/10.1016/j.agee.2023.108721.

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