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Impact of Combined Application of Organic Amendments and PSB along with Rock Phosphate on Quality Parameters and Economics in Groundnut – Maize Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Low phosphorus availability can constrain the productivity of groundnut–maize cropping systems, while the direct effectiveness of rock phosphate may be limited by poor solubility. An in situ trial was conducted over two consecutive years (2021-2022 and 2022-2023 for groundnut; 2022 and 2023 for maize) to evaluate the effect of rock phosphate (RP) combined with organic amendments (vermicompost, FYM and humic acid) and phosphate-solubilising bacteria (PSB) on the quality, yield and

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economics of a groundnut-maize cropping system. Fourteen integrated nutrient management (INM) treatments were compared, ranging from an unfertilised control to a fully integrated package (100% RP + vermicompost + FYM + humic acid + PSB). The results showed that the quality parameters of groundnut (protein and oil content and yield, kernel yield and shelling percentage) and maize (protein content and yield) improved significantly and progressively with the successive integration of organic and microbial inputs. The fully integrated treatment (T14) recorded the highest values across the parameters, followed by T13 and T12, whereas the control recorded the lowest. Economic analysis revealed that, although the cost of cultivation increased progressively with input intensity, gross income and the benefit-cost ratio increased more sharply, with T14 giving the highest B:C ratio in both groundnut (2.33) and maize (2.44). The groundnut equivalent yield (GEY) of the cropping system also more than doubled under T14 (39.34 q/ha) relative to the control (17.95 q/ha). The combined application of rock phosphate, vermicompost, FYM, humic acid and PSB was the best-performing treatment under the study conditions.

Keywords: *Rock phosphate; phosphate-solubilising bacteria; vermicompost; farmyard manure; integrated nutrient management; groundnut–maize cropping system; protein yield; oil yield.*

1. Introduction

Groundnut (*Arachis hypogaea* L.) and maize (*Zea mays* L.) are two of the most important crops in rainfed and semi-arid cropping systems of India, together contributing significantly to edible oil security, protein nutrition and cereal-based food and feed supply. Continuous cultivation under these systems, however, is frequently constrained by low native phosphorus availability, particularly in soils with high fixation capacity, where a large fraction of applied phosphatic fertiliser becomes unavailable to plants shortly after application. Rock phosphate, a low-cost indigenous source of phosphorus, offers a viable alternative to costly water-soluble fertilisers such as SSP and DAP, but its direct agronomic efficiency is often limited by poor solubility, especially in neutral to alkaline soils. Integrated nutrient management, combining mineral phosphate sources with organic amendments (FYM, VC and humic acid) and microbial inoculants such as PSB, has emerged as a sustainable strategy to enhance the solubilisation and availability of rock phosphate while simultaneously improving soil organic matter, microbial activity and nutrient-use efficiency. Recent field studies in groundnut and maize further indicate that integrated nutrient management combining organic and mineral nutrient sources can improve crop productivity and economic performance relative to sole-source nutrient management (Babu *et al*., 2024; Dayal *et al*., 2026; Htun *et al*., 2025; Maurya *et al*., 2024). Comparable improvements under integrated nutrient management have also been reported in maize (Channabasavanna *et al*., 2007; Pandit *et al*., 2025). PSB inoculation further complements this process by solubilising fixed soil and rock phosphate through organic acid secretion and phosphatase activity, thereby enhancing phosphorus availability and indirectly promoting nodulation and biological nitrogen fixation in legumes (Jiang *et al*., 2021). Field evidence in groundnut has also shown that PSB inoculation used with phosphorus fertilisation can improve crop growth and yield compared with sole inorganic fertilisation, supporting microbial phosphorus mobilisation as a component of integrated nutrient management (Das Mohapatra *et al*., 2024). Humic acid has been reported to support higher yield and quality in both legume and cereal crops (Li *et al*., 2019; Talavia *et al*., 2007). The specific gap addressed in this study is the absence, within the tested groundnut-maize system, of an integrated assessment of rock phosphate combined with vermicompost, FYM, humic acid and PSB across crop quality, system productivity and economic outcomes over consecutive years. The present study evaluates the effect of the conjoint application of rock phosphate, organic amendments and PSB on quality parameters, yield, GEY and economics of the groundnut-maize cropping system over two consecutive years.

2. Materials and Methods

Field experiments were conducted over two consecutive years during the rabi seasons (groundnut, 2021-2022 and 2022-2023) and kharif seasons (maize, 2022 and 2023) at ARS, Chhatabar Farm, IAS, SOADU. The soil was sandy loam and moderately acidic in reaction. Fourteen treatments were laid out in a randomised block design (RBD) with three replications. The treatments were T_1 - Control; T_2 - 100% RP; T_3 - 50% RP + 50% SSP; T_4 - 100% RP + PSB; T_5 - 100% RP + FYM; T_6 - 100% RP + humic acid (HA); T_7 - 100% RP + vermicompost (VC); T_8 - 100% RP + vermicompost + PSB; T_9 - 100% RP + FYM + PSB; T_{10} - 100% RP + humic acid + PSB; T_{11} - 100% RP + FYM + humic acid + PSB; T_{12} - 100% RP + vermicompost + humic acid + PSB; T_{13} - 100% RP + vermicompost + FYM + PSB; and T_{14} - 100% RP + vermicompost + FYM + humic acid + PSB. During the rabi season, the groundnut variety Dharani was sown at the recommended spacing and seed rate, followed by kharif maize sown sequentially on the same plots to constitute the groundnut-maize cropping system. Rock phosphate, vermicompost, SSP, FYM and humic acid were applied as basal doses at sowing according to the treatment plan, whereas PSB was applied as a seed/soil inoculant following the recommended package of practices for the respective crops. All other agronomic practices, including irrigation, weeding and plant protection measures, were kept uniform across treatments. Quality parameters of groundnut and maize, such as protein and oil contents and their respective yields, were estimated using standard methods. Protein content was determined by estimating the total nitrogen content of groundnut kernels and maize grain, respectively, and multiplying the values by 6.25. The oil content of groundnut kernels was determined using the Soxhlet extraction method. The cost of cultivation, gross income and B:C ratio were computed based on prevailing input costs and market prices of produce for each treatment. Groundnut equivalent yield (GEY) of the cropping system was calculated by converting maize yield into groundnut-equivalent terms using the prevailing price ratio of the two commodities and adding it to groundnut yield to obtain a single comparable measure of system productivity. Data recorded for both years were statistically analysed year-wise and pooled over years using analysis of variance (ANOVA) appropriate for an RBD.

3. Results and Discussions

Pooled mean data over two years (2021-2022 and 2022-2023) for quality parameters such as protein content (%), protein yield (kg ha^{-1}), oil content (%), oil yield (kg ha^{-1}), kernel yield (kg ha^{-1}) and shelling percentage of groundnut are presented in Table 1.

Table 1. Effect of rock phosphate in combination with organic amendments and microbial inoculum on quality parameters of Rabi groundnut (pooled mean, 2021-22 & 2022–23)

Treatments		Protein %	Protein yield (kg ha^{-1})	Oil %	Oil yield (kg ha^{-1})	Kernel yield (kg ha^{-1})	Shelling %
T1	Control	18.47	124.52	40.83	275.55	674.83	65.357
T2	100% RP	19.45	169.63	41.57	362.69	872.33	70.961
T3	50% RP + 50% SSP	20.88	202.51	42.50	412.65	971.00	72.041
T4	100% RP+ PSB	21.45	227.55	42.52	451.62	1062.50	73.436
T5	100% RP + FYM	21.52	251.39	43.80	512.42	1168.67	73.810
T6	100% RP+ Humic Acid (HA)	20.82	234.18	43.38	488.05	1125.00	73.457
T7	100 % RP + Vermicompost (VC)	22.57	286.35	47.23	599.42	1269.50	74.029
T8	100% RP + Vermicompost +PSB	26.35	365.56	48.63	692.14	1423.00	76.199
T9	100 % RP + FYM + PSB	26.18	356.03	48.53	662.28	1396.17	74.918
T10	100 % RP + Humic Acid +PSB	25.03	354.37	47.43	652.37	1344.00	74.294
T11	100% RP + FYM + Humic Acid + PSB	27.65	402.00	48.98	712.53	1455.00	76.248
T12	100 % RP + Vermicompost + Humic Acid + PSB	29.67	464.29	50.40	788.74	1565.50	76.604
T13	100% RP + Vermicompost + FYM + PSB	30.78	548.12	52.03	927.23	1781.50	76.702
T14	100% RP + Vermicompost+ FYM + Humic Acid+ PSB	32.37	619.27	52.72	1009.15	1913.67	77.467
CD		0.903	18.106	0.740	29.013	55.199	1.841

The results indicated that the quality parameters were significantly influenced by the integrated nutrient management treatments during both years of experimentation and in the pooled analysis. The lowest values were recorded with T1, i.e., 18.47%, 124.52 kg ha^{-1}, 40.83% and 275.55 kg ha^{-1} for protein content, protein yield, oil content and oil yield, respectively, whereas T14 produced the highest values for protein content (32.37%), protein yield (619.27 kg ha^{-1}), oil content (52.72%) and oil yield (1009.15 kg ha^{-1}). It was followed by T13 (100% RP + vermicompost + FYM + PSB; 30.78% and 548.12 kg ha^{-1}) and T12 (100% RP + vermicompost + humic acid + PSB).

Kernel yield and shelling percentage are important quality and market-value traits and improved significantly with integrated nutrient management. The lowest values for kernel yield (674.83 kg/ha, pooled mean) and shelling percentage (65.357%, pooled mean) were recorded with T1, whereas the highest values were recorded with T14 (1913.67 kg/ha and 77.467%, respectively).

The progressive increase in protein and oil content, along with kernel yield and shelling percentage, with the successive addition of organic amendments and PSB to rock phosphate indicates gradual improvement in nutrient content and uptake. VC and FYM supply readily mineralisable nutrients along with growth-promoting substances such as auxins, cytokinins and humic-like compounds that stimulate root proliferation, thereby increasing nutrient absorption and translocation to developing kernels (Chavan *et al*., 2019; Dadhich *et al*., 2021). Application of PSB along with rock phosphate is known to enhance the release of fixed soil phosphorus through organic acid secretion and phosphatase activity, which indirectly promotes nodulation and symbiotic nitrogen fixation in legumes, ultimately resulting in higher seed quality parameters such as protein and oil accumulation (Jiang *et al*., 2021). Sen *et al*. (2022) reported increased oil and protein parameters with the combined application of vermicompost and poultry manure in groundnut.

Humic acid, present in T6, T10, T11, T12 and T14, is reported to improve nutrient chelation and root-cell membrane permeability, thereby facilitating greater nitrogen and micronutrient uptake and, consequently, higher protein synthesis in legume seeds. This is consistent with the findings of Li *et al*. (2019). Similarly, Talavia *et al*. (2007) reported that soil application of humic acid along with the recommended dose of fertiliser significantly improved the growth, yield and quality parameters of groundnut, corroborating the superior performance of humic-acid-containing treatments (T11, T12 and T14) observed in the present study. This pattern reinforces the principle of integrated nutrient management (INM), wherein organic manures, PSB and humic acids act complementarily rather than redundantly.

The improvement in shelling percentage can be attributed to the enhanced availability of calcium and phosphorus in the pegging zone, which are known to influence pod and kernel development and the ratio of kernel to shell weight.

The data in Table 2 represent the protein content (%) and protein yield (kg/ha) of maize grain as influenced by different integrated nutrient management treatments, pooled over two years. Protein content and protein yield followed closely parallel trends because protein yield is a function of both grain protein concentration and grain yield. The lowest protein content (6.67%, pooled mean) was recorded under the control (T1), while a progressive and significant increase was observed with the successive combination of organic manures, vermicompost, humic acid and RP, with T14 recording 12.62%, followed by T13 and T12. The magnitude of improvement in protein content and protein yield recorded in the present study is consistent with the findings of Moeinnamini *et al*. (2024) and Gao *et al*. (2020) on integrated bio-organic nutrient management and maize protein content.

Data on the cost of cultivation (₹/ha), gross income (₹/ha) and benefit-cost (B:C) ratio of groundnut, as influenced by different integrated nutrient management treatments and pooled over two years, are presented in Table 3. The results revealed that the cost of cultivation increased progressively from the control (T1; ₹68,159.17/ha, pooled mean) to the fully integrated treatment T14 (100% RP + vermicompost + FYM + humic acid + PSB; ₹78,708.51/ha), reflecting the additional input costs of vermicompost, FYM, humic acid and PSB inoculant incorporated progressively across treatments. Gross income showed a substantially larger increase across treatments than the cost of cultivation. The lowest gross income (₹101,705.28/ha, pooled mean) was recorded under the control (T1), while the highest was recorded under T14 (₹183,769.27/ha), followed by T13 and T12. The B:C ratio, which reflects the economic efficiency of the investment in nutrient management, increased consistently from 1.49 under the control to a maximum of 2.33 under T14 (100% RP + vermicompost + FYM + humic acid + PSB), followed by T13 and T12. This trend closely mirrors the pod, kernel and haulm yield advantages recorded under these treatments, indicating that the higher biological productivity achieved through the integration of organic manures, vermicompost, humic acid and PSB with rock phosphate translated into proportionately higher market realisation.

Table 2. Effect of rock phosphate in combination with organic amendments and microbial inoculum on quality parameters of Kharif Maize (pooled mean, 2022 & 2023)

Treatments		Protein content (%)	Protein yield
T1	Control	6.67	153.28
T2	100% RP	7.48	179.28
T3	50% RP + 50% SSP	8.78	275.27
T4	100% RP+ PSB	8.63	289.71
T5	100% RP + FYM	9.23	333.23
T6	100% RP+ Humic Acid (HA)	8.95	318.30
T7	100 % RP + Vermicompost (VC)	9.50	346.52
T8	100% RP + Vermicompost +PSB	9.92	369.73
T9	100 % RP + FYM + PSB	9.85	369.30
T10	100 % RP + Humic Acid +PSB	9.60	355.79
T11	100% RP + FYM + Humic Acid + PSB	10.68	405.95
T12	100 % RP + Vermicompost + Humic Acid + PSB	10.75	421.69
T13	100% RP + Vermicompost + FYM + PSB	11.60	477.90
T14	100% RP + Vermicompost+ FYM + Humic Acid+ PSB	12.62	558.42
CD		0.570	27.683

Table 3. Effect of rock phosphate in combination with organic amendments and microbial inoculum on benefit cost ratio of rabi groundnut (pooled mean, 2021-22 & 2022-23)

Treatments		Cost of cultivation (₹/ha)	Gross income (₹/ha)	B:C
T1	Control	68159.17	101705.28	1.49
T2	100% RP	70584.23	106136.13	1.50
T3	50% RP + 50% SSP	71367.50	129289.92	1.81
T4	100% RP+ PSB	72515.00	140303.71	1.93
T5	100% RP + FYM	73685.83	147114.89	1.99
T6	100% RP+ Humic Acid (HA)	75066.67	150109.24	1.99
T7	100 % RP + Vermicompost (VC)	75836.67	151937.76	2.00
T8	100% RP + Vermicompost +PSB	76730.00	154835.25	2.01
T9	100 % RP + FYM + PSB	77025.33	153630.55	1.99
T10	100 % RP + Humic Acid +PSB	77081.67	156040.50	2.02
T11	100% RP + FYM + Humic Acid + PSB	77405.00	159012.89	2.05
T12	100 % RP + Vermicompost + Humic Acid + PSB	78043.33	163378.54	2.09
T13	100% RP + Vermicompost + FYM + PSB	78316.67	171381.42	2.19
T14	100% RP + Vermicompost+ FYM + Humic Acid+ PSB	78708.51	183769.27	2.33
CD		8274.354	2228.705	

The data in Table 4 revealed that the cost of cultivation increased progressively from the control (T1; ₹49,896.50/ha, pooled mean) to the fully integrated treatment T14 (100% RP + vermicompost + FYM + humic acid + PSB; ₹61,933.33/ha), reflecting the cumulative expenditure incurred on vermicompost, FYM, humic acid and PSB inoculant added progressively across the treatment gradient. The increase in cultivation cost from T1 to T14 (24%) was moderate relative to the substantially larger gain recorded in gross income under the same treatments, indicating that the additional investment in organic and biological inputs was economically justified by the resulting productivity response.

Gross income showed a markedly larger and more consistent increase across treatments than the cost of cultivation. The lowest gross income (₹63,093.97/ha, pooled mean) was recorded under the control (T1), while the highest was recorded under T14 (₹151,178.90/ha), followed by T13 (100% RP + vermicompost + FYM + PSB; ₹142,386.10/ha) and T12 (₹124,948.30/ha), representing an increase of nearly 140% for the best treatment relative to the control. The B:C ratio increased consistently from 1.26 under the control (T1) to a maximum of 2.44 under T14, followed by T13 (2.33) and T8 (2.07).

Table 4. Effect of rock phosphate in combination with organic amendments and microbial inoculum on benefit cost ratio of kharif maize (pooled mean, 2022 & 2023)

Treatments		Cost of cultivation (₹/ha)	Gross income (₹/ha)	B:C
T1	Control	49896.50	63093.97	1.26
T2	100% RP	50160.83	75034.26	1.49
T3	50% RP + 50% SSP	50343.33	82291.49	1.63
T4	100% RP+ PSB	51033.33	88329.54	1.73
T5	100% RP + FYM	52116.67	93183.09	1.78
T6	100% RP+ Humic Acid (HA)	54150	97218.36	1.79
T7	100 % RP + Vermicompost (VC)	56066.67	104796.3	1.86
T8	100% RP + Vermicompost +PSB	56450	117108	2.07
T9	100 % RP + FYM + PSB	56883.33	112033.8	1.96
T10	100 % RP + Humic Acid +PSB	58533.33	109930.9	1.87
T11	100% RP + FYM + Humic Acid + PSB	60650	116659.6	1.92
T12	100 % RP + Vermicompost + Humic Acid + PSB	61250	124948.3	2.03
T13	100% RP + Vermicompost + FYM + PSB	61033.33	142386.1	2.33
T14	100% RP + Vermicompost+ FYM + Humic Acid+ PSB	61933.33	151178.9	2.44
CD		5650.213	4342.623	

This pronounced improvement in gross income closely mirrors the grain and stover yield advantages typically associated with such integrated packages, indicating that the higher biological productivity achieved through the combined use of organic manures, vermicompost, humic acid and PSB with rock phosphate translated directly into higher market realisation.

Table 5. Effect of rock phosphate in combination with organic amendments and microbial inoculum on Groundnut equivalent yield* (Q ha^{-1}) of the groundnut-maize cropping system (pooled mean, 2022 & 2023)

Treatments		2022	2023	Pooled mean
T1	Control	18.75	17.15	17.95
T2	100% RP	22.01	19.56	20.78
T3	50% RP + 50% SSP	24.99	22.80	23.90
T4	100% RP+ PSB	25.99	24.90	25.44
T5	100% RP + FYM	27.56	28.11	27.84
T6	100% RP+ Humic Acid (HA)	26.62	27.36	26.99
T7	100 % RP + Vermicompost (VC)	28.79	29.55	29.17
T8	100% RP + Vermicompost +PSB	30.93	32.01	31.47
T9	100 % RP + FYM + PSB	30.04	31.36	30.56
T10	100 % RP + Humic Acid +PSB	29.32	31.07	30.34
T11	100% RP + FYM + Humic Acid + PSB	31.02	32.23	31.62
T12	100 % RP + Vermicompost + Humic Acid + PSB	32.73	34.07	33.40
T13	100% RP + Vermicompost + FYM + PSB	35.29	38.43	36.86
T14	100% RP + Vermicompost+ FYM + Humic Acid+ PSB	39.20	39.47	39.34
CD		1.214	1.108	0.787

Data in Table 5 revealed the groundnut equivalent yield pooled over two years for the groundnut-maize cropping system. The lowest GEY (17.95 q/ha, pooled mean) was recorded under the control (T1), whereas T14 (100% RP + vermicompost + FYM + humic acid + PSB) recorded the highest pooled mean of 39.34 q/ha, followed by T13 and T12. The system productivity gain recorded here, with GEY more than doubling under the fully integrated treatment relative to the control, reflects the compounded effect of improved nutrient management on both component crops of the sequence because GEY integrates the productivity of both groundnut and the succeeding maize crop into a single comparable unit expressed on a groundnut price-equivalent basis. This magnitude of system-level improvement is consistent with the findings of Bana *et al*. (2024) and Sande *et al*. (2024). The comparatively modest GEY advantage of sole rock phosphate (T2; 20.78 q/ha, 15.7% increase) relative to the larger gains recorded once organic and biological amendments were introduced (T3 onwards, 33.1% and above) reaffirms that mineral phosphorus supplementation alone is insufficient to realise the full productivity potential of the groundnut-maize system on the soils under study. This observation parallels that of Rahevar *et al*. (2024).

4. Conclusion

The study demonstrates that integrating rock phosphate with vermicompost, FYM, humic acid and PSB produced synergistic rather than additive benefits by enhancing nutrient mineralisation, phosphorus solubilisation, root proliferation and nitrogen fixation, which collectively improved seed quality, yield attributes and system productivity in the groundnut-maize sequence. Sole application of rock phosphate gave only marginal gains, indicating that mineral phosphorus alone did not realise the full yield and quality potential of the system under the study conditions. The treatment combining rock phosphate with vermicompost, FYM, humic acid and PSB (T14) emerged as the agronomically and economically superior option, recording the highest quality parameters, groundnut equivalent yield and benefit-cost ratio. Under the conditions of this study, this treatment may be considered a suitable INM strategy for enhancing the productivity and profitability of the groundnut-maize cropping system.

5. Limitation

The study was conducted at a single experimental location with sandy loam, moderately acidic soil and covered two consecutive cropping cycles. Consequently, the observed treatment responses are specific to the tested site, seasons and management conditions. The study does not report multi-location validation or longer-term assessment of residual effects beyond the study period. Further evaluation across contrasting soils, seasons and locations would be required before extending the findings beyond conditions comparable to those of the present experiment.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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