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Evaluating the impact combined application of organic amendments and PSB with rock phosphate on soil microbial properties in kharif maize under red lateritic soils of Odisha

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Abstract

A field trial was carried out for two year (2022 & 2023) implementing different organic amendments and PSB, determining its biosolubilization potential on rock phosphate in Kharif Maize at ARS, Chhatabara farm, Institute of Agricultural Sciences, SOADU with fourteen treatments and three replications laid out in RBD. The fourteen treatments, T₁- Control; T₂- 100% RP; T₃-50% RP + 50% SSP; T₄- 100% RP+ PSB; T₅- 100% RP + FYM; T₆-100% RP+ Humic Acid (HA); T₇- 100% RP + Vermicompost (VC); T₈- 100% RP + Vermicompost +PSB; T₉- 100% RP + FYM + PSB; T₁₀- 100% RP + Humic Acid +PSB; T₁₁- 100% RP + FYM + Humic Acid + PSB; T₁₂- 100% RP + Vermicompost + Humic Acid + PSB; T₁₃ - 100% RP + Vermicompost + FYM + PSB; T₁₄-100% RP + Vermicompost+ FYM + Humic Acid+ PSB. Analysing the yield of kharif Maize and soil microbial activities, it was noted that T₁₄ showed maximum grain and stover yield with pooled mean of 4419.33 kg ha⁻¹ and 4712.50 kg ha⁻¹ respectively. Soil microbial activities were studies during different growth stages of maize and regression studies (R², r) were done with respective to grain yield. It was noted that the microbial properties such as microbial biomass carbon and microbial biomass phosphorus reached its peak during pod development and filling stages which decreases gradually towards physiological maturity.

Keywords: MBC, MBP, grain yield, stover yield, Maize

Introduction

Among the macronutrients essential to plant growth, phosphorus occupies a central position, shaping processes ranging from root development and seed formation to nutrient uptake, photosynthesis, respiration and the timely completion of the crop cycle (Hinsinger, 2001) ^[7]. Maize shows vulnerability towards iron toxicity, demanding for proper and sufficient drainage and soil ameliorations. The principal sources of rock phosphorus are considered as the sedimentary rocks which has a lion's contribution of 80% of entire global RP stocks. Fluorapatite-rich phosphate rocks supposed to have higher reactivity amongst its various forms, considerably most suitable for direct application as a reliable source of phosphorus in agriculture. Use of Organic amendments such as farmyard manure (FYM) and vermicompost not only contribute additional nutrients but also create a conducive environment for microbial activity. Meanwhile, the introduction of phosphate-solubilizing microorganisms (PSMs) plays a key role in mobilizing phosphorus from rock phosphate, thereby improving its uptake by plants (Khan *et al.*, 2010) ^[8]. Humic acids, as the principal components of soil organic matter, play a vital role in enhancing plant growth and soil health (Nardi *et al.*, 2002) ^[9]. Empirical studies have shown that humic acids improve soil structure, increase water retention, reduce bulk density, and elevate total porosity and organic matter content. MBC and MBP respond to changes in management practices (organic amendments, fertilization, tillage) much faster than total soil carbon or phosphorus, which changes only over years or decades. It also acts as both a sink and a sources of plant available phosphorus. Since the work focuses on rock phosphates solubilisation using organic amendments and microbial inoculants, MBP directly reflects how effectively the introduced/ native microbial population is mobilizing and cycling phosphorus from the applied rock phosphate.

Higher MBC under organic amendments or PSB treatments indicates a more active, functionally robust microbial community capable of sustaining nutrient availability across the maize growing season.

Materials and Methods

A field experiment was conducted at ARS, Chhatabar farm, IAS, SOADU, Bhubaneswar in kharif season of 2022 and 2023 to determine the impact of combined organic amendments and PSB on solubilisation potential of rock phosphate with Maize crop (Indra 017). The trial was laid out in Randomised Block design with fourteen treatments replicated thrice. The fourteen treatments namely, T₁- Control; T₂- 100% RP; T₃-50% RP + 50% SSP; T₄- 100% RP+ PSB; T₅- 100% RP + FYM; T₆-100% RP+ Humic Acid (HA); T₇- 100% RP + Vermicompost (VC); T₈-100% RP + Vermicompost +PSB; T₉- 100% RP + FYM + PSB; T₁₀- 100% RP + Humic Acid +PSB; T₁₁- 100% RP + FYM + Humic Acid + PSB; T₁₂- 100% RP + Vermicompost + Humic Acid + PSB; T₁₃ - 100% RP + Vermicompost + FYM + PSB; T₁₄-100% RP + Vermicompost+ FYM + Humic Acid+ PSB. Soil samples were collected with proper precautionary measures from maize field at different growth stages (i.e. 30, 60, 90, and at harvest) from 0-15 cm depth at each treatment plot for investigating soil microbial properties such as microbial biomass carbon and microbial biomass phosphorus. Soil microbial biomass carbon is determined by chloroform fumigation-extraction method (Vance *et al.*, 1987) [13] and microbial biomass phosphorus was determined by chloroform fumigation-extraction method of Brookes *et al.*, 1982, with modifications by Hedley and Stewart (1982) [6]. Collected soil samples were air-dried lightly, sieved (2mm), and stored moist at 4 °C prior to analysis. The soil of the experimental plot was determined to be sandy loam and moderately acidic (pH-5.68). At harvest the grain and stover yield was recorded and segregated according to treatment plan. All the statistical analysis such as mean, pooled mean, ANOVA and

regression studies were carried out using Microsoft Excel at 5% and 1% significance to draw a corroborative result.

Results and Discussion

The data in Table 1 represents grain and stover yield (kg ha⁻¹) of kharif maize as influenced by rock phosphate applied in combination with organic amendments and PSB, pooled over 2022 and 2023.

Grain yield ranged from 2297.33 kg ha⁻¹ in the control (T₁) to 4419.33 kg ha⁻¹ in T₁₄ (100% RP + Vermicompost + FYM + Humic acid + PSB), an increase of about 92 per cent over the control. Stover yield followed an identical trend, ranging from 2757.50 kg ha⁻¹ (T₁) to 4712.50 kg ha⁻¹ (T₁₄), an increase of about 71 per cent. Treatment T₁₄ recorded the significantly highest grain and stover yield, remaining statistically at par with T₁₃ (4115.00 and 4394.67 kg ha⁻¹, respectively) and significantly superior to all remaining treatments. Sole application of RP (T₂) produced only a marginal yield improvement over the control, whereas combining RP with a single organic source (T₅, T₆, T₇) nearly doubled the yield gain, and further inoculation with PSB (T₈-T₁₄) consistently improved yield over the corresponding non-inoculated treatment.

The substantial increase in grain and stover yield under integrated nutrient management can be attributed to enhanced phosphorus availability, improved uptake and increased soil biological activities. Application of organic amendments and PSB accelerates its dissolution through the production of organic acids, thereby increasing phosphorus availability throughout the crop growth period. (Ditta *et al.*, 2022; Ali S *et al.*, 2022) [2, 1].

Higher phosphorus availability enhances photosynthesis, ATP synthesis, carbohydrate metabolism, and assimilate translocation from source leaves to developing grains. The superior performance of T₁₄ indicates a strong synergistic interaction among vermicompost, FYM, humic acid and PSB resulting in maximum nutrient use efficiency.

Table 1: Effect of rock phosphate in combination with organic amendments and microbial inoculum on grain and stover yield (kg ha⁻¹) of kharif maize (pooled mean, 2022–2023)

Treatment	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)
T ₁ - Control	2297.33	2757.50
T ₂ - 100% RP	2396.00	2880.00
T ₃ - 50% RP + 50% SSP	3135.50	3292.67
T ₄ - 100% RP+ PSB	3357.67	3615.00
T ₅ - 100% RP + FYM	3608.17	3844.67
T ₆ - 100% RP+ Humic Acid (HA)	3552.67	3751.67
T ₇ - 100% RP + Vermicompost (VC)	3642.17	3901.00
T ₈ - 100% RP + Vermicompost +PSB	3744.50	4003.17
T ₉ - 100% RP + FYM + PSB	3725.83	3927.33
T ₁₀ - 100% RP + Humic Acid +PSB	3700.17	3961.33
T ₁₁ - 100% RP + FYM + Humic Acid + PSB	3793.67	4100.83
T ₁₂ - 100% RP + Vermicompost + Humic Acid + PSB	3920.33	4190.33
T ₁₃ - 100% RP + Vermicompost + FYM + PSB	4115.00	4394.67
T ₁₄ - 100% RP + Vermicompost+ FYM + Humic Acid+ PSB	4419.33	4712.50
SEm±	29.366	21.618
CD (p=0.05)	81.803	60.219

The data in Table 2 represents pooled data (2022 & 2023) on soil microbial biomass phosphorus as influenced by combined application of rock phosphorus in conjuncture with organic amendments and PSB in kharif maize, as observed at 30 DAS, 60 DAS, 90 DAS and harvest.

Irrespective of treatment, MBP followed a similar temporal pattern, increasing steadily from 30 DAS to attain a peak value at 60 DAS, followed by a significant decline at 90 DAS and a further decrease at harvest. Averaged across treatments, MBP increased

from a mean of 32.6 µg g⁻¹ at 30 DAS to 47.9 µg g⁻¹ at 60 DAS, before declining to 44.6 µg g⁻¹ at 90 DAS and 41.0 µg g⁻¹ at harvest.

Among treatments, the lowest MBP was recorded under the absolute control (T₁) at all the growth stages (18.98, 23.06, 19.22 and 17.52 µg g⁻¹ soil at 30, 60, 90 and at harvest respectively), while T₁₄ (100% RP + Vermicompost+ FYM + Humic Acid+ PSB) recorded the significantly highest MBP at all stages (47.30, 71.20, 66.23 and 61.23 µg g⁻¹ soil respectively), and statistically

at par with T₁₃ and closely followed by T₁₂ and T₁₁. Among the two –component combinations, T₈ (100% RP + Vermicompost +PSB) and T₉ recorded distinctly higher MBP than their

respective PSB-uninoculated counterparts T₇ and T₅, confirming a consistent positive contribution of PSB inoculation across organic carriers.

Table 2: Effect of organic amendments and microbial inoculum with rock phosphate on microbial biomass phosphorus ($\mu\text{g g}^{-1}$ soil) in kharif maize (pooled mean, 2022–2023)

Treatment	30 DAS	60 DAS	90 DAS	Harvest
T ₁ - Control	18.98	23.06	19.22	17.52
T ₂ - 100% RP	20.97	28.10	25.37	21.07
T ₃ - 50% RP + 50% SSP	23.94	32.79	31.23	28.52
T ₄ - 100% RP+ PSB	26.58	39.88	38.80	32.05
T ₅ - 100% RP + FYM	29.78	45.90	43.38	37.72
T ₆ - 100% RP+ Humic Acid (HA)	29.37	44.22	40.09	37.29
T ₇ - 100% RP + Vermicompost (VC)	32.52	49.18	46.74	42.59
T ₈ - 100% RP + Vermicompost +PSB	38.28	55.76	54.31	51.06
T ₉ - 100% RP + FYM + PSB	36.82	54.79	51.76	49.77
T ₁₀ - 100% RP + Humic Acid +PSB	33.91	51.84	49.78	46.52
T ₁₁ - 100% RP + FYM + Humic Acid + PSB	40.57	59.95	58.14	52.24
T ₁₂ - 100% RP + Vermicompost + Humic Acid + PSB	42.17	64.91	62.15	56.35
T ₁₃ - 100% RP + Vermicompost + FYM + PSB	44.28	68.98	65.14	59.21
T ₁₄ - 100% RP + Vermicompost+ FYM + Humic Acid+ PSB	47.30	71.20	66.23	61.23
CD (p=0.05)	1.556	1.697	2.431	2.075

FYM, VC and humic acid supply readily oxidisable carbon and other nutrients that serve as an energy source for heterotrophic soil microflora, hereby stimulating microbial multiplication and immobilisation of soil P into the living biomass fraction (Fei, C., *et al.*, 2024) [4]. The synergism observed when a organics and PSB were applied together may be attributed to the organic substrate

providing a more favourable microenvironment for survival, multiplication and metabolic activity of the inoculated PSB population, which otherwise faces poor establishment when applied alone with an inorganic carrier such as RP (Elhaisoufi *et al.*, 2022) [3].

Table 3: Effect of organic amendments and microbial inoculum with rock phosphate on microbial biomass carbon ($\mu\text{g g}^{-1}$ soil) in kharif maize (pooled mean, 2022–2023)

Treatment	30 DAS	60 DAS	90 DAS	Harvest
T ₁ - Control	118.97	152.53	138.41	130.40
T ₂ - 100% RP	139.29	176.62	159.20	149.52
T ₃ - 50% RP + 50% SSP	151.71	193.50	174.74	166.86
T ₄ - 100% RP+ PSB	160.60	201.92	183.27	176.37
T ₅ - 100% RP + FYM	168.81	216.21	194.46	187.17
T ₆ - 100% RP+ Humic Acid (HA)	164.93	207.68	189.50	180.81
T ₇ - 100% RP + Vermicompost (VC)	178.43	227.00	206.00	193.65
T ₈ - 100% RP + Vermicompost +PSB	194.81	247.48	223.34	210.14
T ₉ - 100% RP + FYM + PSB	190.55	240.73	218.55	203.61
T ₁₀ - 100% RP + Humic Acid +PSB	183.93	232.23	210.93	194.93
T ₁₁ - 100% RP + FYM + Humic Acid + PSB	199.71	254.34	230.81	221.90
T ₁₂ - 100% RP + Vermicompost + Humic Acid + PSB	208.56	265.94	242.07	230.45
T ₁₃ - 100% RP + Vermicompost + FYM + PSB	216.52	273.16	248.73	234.26
T ₁₄ - 100% RP + Vermicompost+ FYM + Humic Acid+ PSB	228.01	291.29	261.60	249.46
CD (p=0.05)	1.958	3.036	1.967	3.723

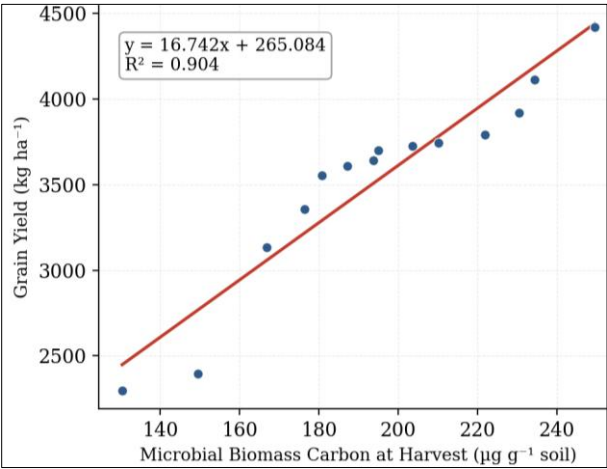
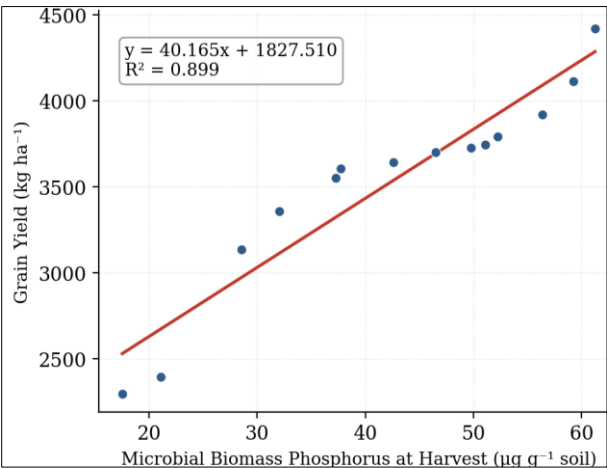
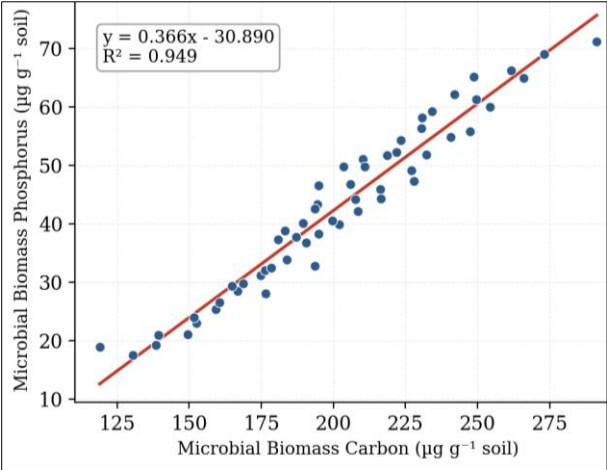
The data in table 3 represents pooled data on soil microbial biomass carbon over 2022 and 2023 as influenced by the treatments at 30, 60, 90 DAS and harvest of kharif Maize. The control (T₁) recorded the lowest MBC at all stages (118.97 to 152.53 $\mu\text{g g}^{-1}$ soil), while T₁₄ recorded the significantly highest MBC throughout (228.01, 291.29, 261.60 and 249.46 $\mu\text{g g}^{-1}$ soil at 30, 60, 90 DAS and harvest, respectively), on par with T₁₃ and significantly superior to the remaining treatments. The ranking of treatments for MBC closely mirrored that observed for MBP, dehydrogenase and acid phosphatase, with the four-component combination (RP + Vermicompost + FYM + Humic acid + PSB) and the three-component combinations involving Vermicompost or FYM together with PSB consistently occupying the top positions, and sole RP or RP + SSP treatments remaining close to the control.

MBC represents the living, actively cycling fraction of soil

organic carbon and is recognised as a sensitive early indicator of changes in soil biological fertility, generally responding to management practices well before changes become detectable in total soil organic carbon. The close parallelism between the trends in MBC and MBP across treatments and growth stages further suggest a fairly stable microbial biomass C:P ratio in this soil, so that any treatment enhancing the total size of the microbial biomass proportionately enhanced the amount of phosphorus held within it. The decline in MBC after 60 DAS may be explained by reduced rhizodeposition and organic substrate availability during the reproductive and maturity phases of maize, coupled with turnover and mineralization of the microbial biomass built up earlier in the season, part of which have contributed to the nutrient pool utilised by the crop during grain filling (Niedeggen, D., *et al* 2024; Pausch, J., & Kuzyakov, Y. 2018) [10, 11].

Table 4: Regression equations describing the relationship among soil microbial biomass phosphorus and yield in kharif maize (pooled data)

Relationship (Y on X)	Regression equation	R ²	r	Significance
MBP on MBC	Y = 0.366X - 30.890	0.949	0.974	significant at 1% level
Grain yield on MBP	Y = 40.165X + 1827.510	0.899	0.948	significant at 1% level
Grain yield on MBC	Y = 16.742X + 265.084	0.904	0.951	significant at 1% level



The regression of MBP on MBC gave the equation $Y = 0.366X - 30.890$, with a very high coefficient of determination ($R^2 = 0.949$), indicating that nearly 94.9 per cent of the variation in microbial biomass phosphorus across treatments and growth stages could be explained by the corresponding variation in microbial biomass carbon alone. Microbial biomass carbon ($R^2 = 0.904$) and microbial biomass phosphorus ($R^2 = 0.899$) were the strongest predictors of grain yield. The strong anticipatory relationship between MBC and

MBP and their respective regression with grain yield shows an evidence that the microbial biomass carbon and phosphorus is closely related to productivity of kharif maize with conjoint application of rock phosphate, organic amendments and PSB. (Harish, M.N *et al.*, 2022) ^[5].

Conclusion

Present investigation clearly suggests that the confluence in application of rock phosphate, organic amendments and PSB considerably enhanced both grain and stover yield and biological activities in red lateritic soils of Odisha under a kharif Maize cropping system evaluated over two years. MBP and MBC of soil collected at different growth stages of Maize followed and identical trend with slight increase at 30DAS reaching peak at 69 DAS and then gradually decreasing toward physiological maturity of crop. A strong regression equation developed between MBP and MBC ($R^2 = 0.949$) clarifying that the soil microbial biomass maintained a stable carbon – to- phosphorus ratio across the treatments. Further it was also observed that grain yield and MBC ($R^2 = 0.904$) and MBP ($R^2 = 0.899$) holds a strong relationship. The multicomponent holds a higher value over sole application or two component application as conjoint application played a major role in solubilisation of rock phosphate for increasing P in soil P pool.

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