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Evaluation of micronutrient vermicompost and plant growth promoting rhizobacteria (PGPR) on soil properties and yield of maize (*Zea mays* L.) var. PHM-1

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Abstract
The experiment was conducted on "Evaluation of micronutrient vermicompost and plant growth promoting rhizobacteria (PGPR) on soil properties and yield of maize (*Zea mays* L.) var. PHM-1" NPK (Nitrogen, Phosphorus, Potassium), Zinc, Vermicompost (VC), and Plant Growth-Promoting Rhizobacteria (PGPR) on maize growth, soil properties, and economic outcomes. Through a structured experimental design involving nine different treatments-T_1: (Absolute Control), T_2: (@0% NPK and Zinc @ 0% + @ 50% VC and PGPR), T_3: (@ 0% NPK and Zinc @ 0% + @ 100% VC and PGPR), T_4: (@ 50% NPK and Zinc @ 50% + @ 0% VC and PGPR), T_5: (@ 50% NPK and Zinc @ 50% + @ 50% VC and PGPR), T_6: (@ 50% NPK and Zinc @ 50% + @ 100% VC and PGPR), T_7: (@ 100% NPK and Zinc @ 100% + @ 0% VC and PGPR), T_8: (@ 100% NPK and Zinc @ 100% + @ 50% VC and PGPR), and T_9: (@ 100% NPK and Zinc @ 100% + @100% VC and PGPR). This study evaluates the changes in maize plant height, leaf count, cob length, grain number per cob, and grain yield. Concurrently, it examines the impact of these treatments on soil physical characteristics (bulk density, particle density, pore space, and water holding capacity) and chemical properties (pH, electrical conductivity, organic content, and nutrient availability). The economic feasibility of each treatment is analysed through a detailed cost-benefit ratio calculation, providing insights into the financial implications of various agronomic practices. The results indicate that higher levels of agronomic inputs correlate with increased plant growth, improved soil conditions, and greater economic returns, thereby underscoring the efficacy of integrated nutrient management in enhancing maize productivity and sustainability. This study contributes valuable data to the field of agricultural science, promoting optimized input usage for maximizing agricultural outputs while ensuring environmental stewardship.

Keywords: Micronutrient, vermicompost, PGPR, maize and soil parameters etc.

Introduction
The significance of optimal nutrient management in modern agriculture extends beyond mere crop sustenance to substantially affecting crop productivity, soil health, and economic viability. This research focuses on evaluating the synergistic effects of combining conventional NPK (Nitrogen, Phosphorus, Potassium) fertilization with innovative approaches like Zinc supplementation, Vermicompost (VC), and Plant Growth-Promoting Rhizobacteria (PGPR) to enhance maize growth. Additionally, the study scrutinizes the resultant changes in soil physical and chemical characteristics due to these treatments. Integrated Nutrient Management (INM) practices have been shown to significantly enhance soil quality and crop productivity across various agricultural settings (Shah and Wu, 2019; Wu and Ma, 2015) [11, 15]. Studies indicate that INM practices, which involve the combined use of organic manures and inorganic fertilizers, lead to improved soil carbon stock, enhanced microbial biomass, and increased nutrient use efficiency, which in turn boosts crop yield (Desai *et al*., 2023; Zhang *et al*., 2020) [3, 6]. Furthermore, the use of organic amendments like farmyard manure in combination with chemical fertilizers has demonstrated substantial improvements in soil physical properties and water retention capabilities, vital for sustainable cropping systems (Kumar *et al*., 2020; Noor *et al*., 2020) [6, 10].

The integration of organic and inorganic nutrient sources not only sustains high crop productivity but also mitigates the adverse environmental impacts associated with excessive inorganic fertilizer use, such as greenhouse gas emissions and nutrient leaching (Walling and Vaneeckhaute, 2020; Timsina, 2018) [14, 13].

The strategic application of these integrated practices is crucial for enhancing soil fertility and ensuring the long-term sustainability of agricultural systems (Ladha *et al*., 2005; Janssen, 1993) [7, 5]. By merging chemical and biological soil amendments, this study aims to contribute robust data on their cumulative effects on both crop and soil health, thereby proposing a sustainable model for future agricultural practices. The findings aspire to guide sustainable nutrient management strategies that optimize agricultural output while maintaining economic and environmental integrity.

Materials and Methods

The experiment titled "Evaluation of Micronutrient Vermicompost and Plant Growth Promoting Rhizobacteria (PGPR) on Soil Properties and Yield of Maize (*Zea mays* L.) Var. PHM-1" was conducted at the Soil Science Research Farm, SHUATS, Prayagraj during the *Kharif* season of 2023. Located within the Agro-Ecological Sub Region of the North Alluvium plain zone, the farm features a subtropical climate with extreme temperatures ranging from 4 °C to 46 °C, and an average annual rainfall of about 1100 mm. Soil samples were collected from depths of 0-15 cm and 15-30 cm for analysis.

In table 1 A Randomized Complete Block Design (RCBD) was employed, incorporating nine treatment combinations to assess various levels of NPK, Zinc, Vermicompost (VC), and PGPR. The treatments included: T_1 as the absolute control; T_2 combining 0% NPK and Zinc with 50% VC and PGPR; T_3 using 0% NPK and Zinc with 100% VC and PGPR; T_4 mixing 50% NPK and Zinc with 0% VC and PGPR; T_5 including 50% NPK and Zinc with 50% VC and PGPR; T_6 combining 50% NPK and Zinc with 100% VC and PGPR; T_7 consisting of 100% NPK and Zinc with 0% VC and PGPR; T_8 combining 100% NPK and Zinc with 50% VC and PGPR; T_9 including 100% NPK and Zinc with 100% VC and PGPR. The maize variety PHM-1 was planted following specific cultural practices including land preparation, fertilization, and irrigation. Data on plant growth, soil properties, and yield were collected and analyzed. An economic analysis of each treatment was conducted, considering cultivation costs, returns, and net profits to evaluate the financial viability of each agronomic practice. This comprehensive methodology aimed to explore the synergistic effects of chemical and biological fertilizers on crop production and soil health, promoting sustainable agricultural practices.

Table 1: Treatment Combinations of Maize

Treatment	Treatment combination
T_1	[Absolute Control]
T_2	[@ 0% NPK and Zinc @ 0% + @ 50% VC and PGPR]
T_3	[@ 0% NPK and Zinc @ 0% + @ 100% VC and PGPR]
T_4	[@ 50% NPK and Zinc @ 50% + @ 0% VC and PGPR]
T_5	[@ 50% NPK and Zinc @ 50% + @ 50% VC and PGPR]
T_6	[@ 50% NPK and Zinc @ 50%+ @ 100% VC and PGPR]
T_7	[@ 100% NPK and Zinc @ 100% + @ 0% VC and PGPR]
T_8	[@ 100% NPK and Zinc @ 100% + @ 50% VC and PGPR]
T_9	[@ 100% NPK and Zinc @ 100% + @100% VC and PGPR]

RDF: Recommended dose of fertilizers:
NPK; 120:60:60 Zinc: 15 Kg ha^{-1}
VC; 10t ha^{-1}
PGPR: 200g/10 Kg Seed (rhizobacteria)
[Source: Ahlawat *et al*. (1991) [1] and (Mohammed *et al*. (2015)] [9].

Results and Discussion

The integration of micronutrient-enriched vermicompost with Plant Growth-Promoting Rhizobacteria (PGPR) markedly enhanced soil quality parameters. These enhancements led to increased pore space and water retention capacity, alongside elevated levels of organic carbon and the availability of key nutrients such as nitrogen, phosphorus, potassium and zinc.

In table 2 summarizes the impact of nine treatments on soil physical attributes at two different soil depths (0-15 cm and 15-30 cm). The attributes analyzed include bulk density, particle density, pore space, and water holding capacity. The treatments are designed to assess the effects of various agricultural inputs on these soil properties. The data indicates a gradation in bulk density, with the lowest values observed in Treatment T_1 (1.242 g cm^{-3} at 0-15 cm depth) and the highest in Treatment T_9 (1.274 g cm^{-3} at 15-30 cm depth). Particle density follows a similar trend, with the minimum at 2.431 g cm^{-3} (T_1 at 0-15 cm) and the maximum at 2.451 g cm^{-3} (T_9 at 15-30 cm). Pore space percentages also show variability, with Treatment T_1 displaying the lowest (39.9% at 15-30 cm depth) and Treatment T_9 the highest (43.75% at 0-15 cm depth). Water holding capacity reflects this pattern, ranging from a low of 36.95% (T_1 at 15-30 cm) to a high of 39.55% (T_9 at 15-30 cm). (Das *et al*. 2013) [2]. This dataset underscores the influence of specific treatments on enhancing soil structural properties, which are crucial for improving soil aeration, water retention, and overall soil health conducive to plant growth. These results closely matched the findings (Singh *et al*. 2013) [12].

Table 2: Impact of varying NPK, Zinc, VC and PGPR levels on soil physical characteristics after Maize harvest

Treatment	Treatment Combination	Bulk density		Particle density		Water holding capacity		% pore space	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	[Absolute Control]	1.242	1.246	2.431	2.433	37.55	36.95	40.5	39.9
T_2	[@ 0% NPK and Zinc @ 0% + @ 50% VC and PGPR]	1.245	1.249	2.435	2.437	37.95	37.5	40.9	40.35
T_3	[@ 0% NPK and Zinc @ 0% + @ 100% VC and PGPR]	1.248	1.252	2.437	2.439	38.65	37.95	41.35	40.85
T_4	[@ 50% NPK and Zinc @ 50% + @ 0% VC and PGPR]	1.243	1.247	2.433	2.436	37.75	37.22	40.7	40.12
T_5	[@ 50% NPK and Zinc @ 50% + @ 50% VC and PGPR]	1.254	1.256	2.440	2.442	39.01	38.05	41.8	40.48
T_6	[@ 50% NPK and Zinc @ 50%+ @ 100% VC and PGPR]	1.26	1.262	2.446	2.448	39.85	38.29	42.4	41.4
T_7	[@ 100% NPK and Zinc @ 100% + @ 0% VC and PGPR]	1.247	1.25	2.442	2.446	38.42	37.26	41.02	40.3
T_8	[@ 100% NPK and Zinc @ 100% + @ 50% VC and PGPR]	1.266	1.267	2.448	2.449	38.92	38.35	43.05	41.85
T_9	[@ 100% NPK and Zinc @ 100% + @100% VC and PGPR]	1.273	1.274	2.449	2.451	39.72	39.55	43.75	42.15
	F-test	S	S	NS	NS	S	S	NS	NS
	C.D. at 5%	0.001	0.006	0.002	0.002	0.274	0.272	0.376	0.266
	S.Ed. (+)	0.024	0.014	0.005	0.005	0.623	0.628	0.867	0.614

In table 3 provides a detailed examination of the impact of various treatments involving NPK, Zinc, Vermicompost (VC), and Plant Growth-Promoting Rhizobacteria (PGPR) on soil chemical characteristics after maize harvzest, at two soil depths (0-15 cm and 15-30 cm). The soil parameters measured include pH, electrical conductivity (EC), percentage of organic carbon, and the availability of key nutrients-nitrogen, phosphorus, potassium, and zinc. The data reveal a trend across treatments from T_1 to T_9, indicating gradual changes in soil chemistry. Soil pH generally decreases slightly from T_1 (7.33 at 0-15 cm) to T_9 (7.26 at the same depth), suggesting a slight acidification with increased treatment intensity. Electrical conductivity, a measure of soil salinity, shows an incremental increase across treatments, with T_1 registering 0.285 dS m^{-1} at 0-15 cm depth and T_9 reaching 0.319 dS m^{-1}, reflecting enhanced mineral ion activity in the soil. Organic carbon percentages are fairly consistent across depths but vary slightly among treatments, demonstrating the impact of organic amendments such as VC. Nutrient availability also shows a pattern of increase, with nitrogen, phosphorus, potassium, and zinc levels all rising as the treatments intensify. Notably, zinc availability shows a significant upward trend from 0.46 kg ha^{-1} in T_1 to 0.54 kg ha^{-1} in T_9 at 0-15 cm depth. These results underscore the effectiveness of the applied treatments in enhancing soil fertility, which is critical for sustaining high crop yields and ensuring soil health over time. providing a compelling case for the adoption of integrated nutrient management practices in maize production. These results closely matched the findings Dekhane *et al.* (2011) [4].

Table 3: Impact of varying amounts of NPK, Zinc, VC and PGPR on soil chemical characteristics after Maize plant harvest at depths of 0-15 cm and 15-30 cm

Treatment	Soil pH		EC (dS m^{-1})		Organic Carbon (%)		Available Nitrogen (Kg ha^{-1})		Available Phosphorus (Kg ha^{-1})		Available Potassium (Kg ha^{-1})		Available Zinc (Kg ha^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	7.33	7.35	0.285	0.291	0.415	0.408	270.56	266.95	15.66	14.26	152.63	149.12	0.46	0.48
T_2	7.32	7.34	0.291	0.297	0.420	0.414	271.64	267.85	15.86	14.56	153.55	150.33	0.47	0.49
T_3	7.31	7.33	0.296	0.299	0.426	0.421	272.85	268.55	16.16	15.59	154.2	151.55	0.48	0.49
T_4	7.32	7.35	0.288	0.293	0.418	0.412	273.98	271.68	16.70	15.80	156.95	154.12	0.46	0.48
T_5	7.30	7.31	0.301	0.307	0.434	0.429	275.85	273.21	17.15	16.67	158.92	156.2	0.47	0.50
T_6	7.29	7.30	0.306	0.310	0.439	0.435	277.95	275.23	17.65	16.99	160.13	158.95	0.48	0.51
T_7	7.31	7.32	0.294	0.298	0.427	0.421	280.33	278.55	18.16	17.65	163.01	161.23	0.50	0.54
T_8	7.28	7.29	0.312	0.315	0.449	0.445	283.15	281.95	18.58	17.89	165.55	163.78	0.52	0.56
T_9	7.26	7.27	0.319	0.321	0.461	0.458	286.05	285.20	18.95	18.51	168.23	167.01	0.54	0.57
F-test	NS	NS	S	S	S	S	S	S	S	S	S	S	S	S
C.D. at 5%	0.007	0.009	0.003	0.003	0.041	0.005	1.79	2.15	0.40	0.49	1.84	2.09	0.009	0.011
S.Ed. (+)	0.017	0.021	0.008	0.007	0.061	0.012	1.93	2.35	0.93	1.14	4.23	4.81	0.002	0.026

In table 4 delineates the impact of diverse treatments involving different concentrations of NPK, Zinc, Vermicompost (VC), and Plant Growth-Promoting Rhizobacteria (PGPR) on growth and yield attributes of maize over three developmental stages (30, 60, and 90 days after sowing, DAS). The parameters measured include plant height, leaf count, cob length, number of grains cob^{-1}, test weight (1000 g $grains^{-1}$), and grain yield (quintals per hectare, q ha^{-1}). The results indicate a spectrum of growth responses, with the lowest yield attributes observed in Treatment T_1, showing a plant height of 145.43 cm, leaf count of 7.00, and grain yield of 26.33 q/ha at 90 DAS. Conversely, Treatment T_9 demonstrated the highest yield attributes with a plant height of 175.64 cm, leaf count of 12.60, and grain yield of 44.60 q ha^{-1} at 90 DAS. This data underscores the potential of optimizing agronomic inputs to enhance maize productivity. These results closely matched the findings (Meena *et al*. 2012) [8].

Table 4: Impact of varying amounts of NPK, Zinc, VC and PGPR on growth and yield attributes

Treatment	Plant height (cm)			Leaves $Plant^{-1}$			Length of Cob^{-1} (cm)	No. of Grains Cob^{-1}	Test Weight (1000 g $grains^{-1}$)	Grain Yield (q ha^{-1})
	30 DAS (cm)	60 DAS (cm)	90 DAS (cm)	30 DAS	60 DAS	90 DAS				
T_1	60.51	138.95	145.43	3.14	6.67	7.00	11.13	286.20	193.56	26.33
T_2	64.89	142.68	149.39	4.20	7.80	8.00	12.20	288.40	195.71	28.50
T_3	68.52	146.41	153.32	4.80	8.40	8.60	13.27	290.60	197.86	30.67
T_4	72.47	150.14	157.51	5.20	9.00	9.20	14.34	292.80	200.01	32.84
T_5	76.53	153.88	161.09	5.60	9.60	9.80	15.41	295.00	202.16	35.01
T_6	80.35	157.61	165.38	6.00	10.20	10.40	16.48	297.20	204.31	37.18
T_7	82.48	161.35	169.33	6.40	10.80	11.00	17.05	299.40	206.46	39.35
T_8	84.42	165.02	172.49	6.80	11.60	11.80	17.69	303.55	211.39	41.98
T_9	86.56	168.68	175.64	7.20	12.40	12.60	18.32	307.70	216.31	44.60
F-test	S	S	S	S	S	S	S	S	S	S
C.D. at 5%	3.05	3.40	3.50	0.43	0.62	0.61	0.84	2.36	2.36	2.06
d. (+)	7.03	7.83	8.08	1.41	2.01	1.98	2.74	7.69	7.69	6.17

Summary and Conclusion

The trial was conducted in research farm of SSAC, [NAI], SHUATS, Prayagraj (Allahabad), U.P., India topic taken for the study the topic "Evaluation of micronutrient vermicompost and plant growth promoting rhizobacteria (PGPR) on soil properties and yield of maize (*Zea mays* L.) var. PHM-1" objectives were on soil health parameters chemical parameters i.e. The study revealed significant effects on various soil parameters such as nitrogen, phosphorus, potassium, zinc, organic carbon, particle density, pore space, and water holding capacity. Likewise, significant impacts were observed on maize plant characteristics including height, cob count, yield, and economic aspects of the treatments. the research highlighted the positive influence of macronutrients and zinc on both soil health and maize yield in white pearly maize cultivation. these factors were found to enhance soil fertility, promote healthy plant growth, and improve yield attributes. However, achieving optimal outcomes relies on balanced application and effective management practices.

It is found that the treatment T_9-[@ 100% NPK and Zinc @ 100% + @ 100% VC and PGPR] was found to be at par followed by using different levels of NPK and Zinc in Maize crop with the readings are significantly shown by different combinations with the significant result at 0.05 level in N,P,K, Zinc and OC. Result was found significant with increase in soil fertility and also shown significance on yield parameters with T_8, it has shown the highest yield production followed by T_9. was profitable production on soil productivity and good sustainable soil health.

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