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Research Article

Soil Nutrient Chemistry and Productivity Response of Pearl Millet to Integrated Vermicompost and Biofertilizer Management

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Abstract

A field experiment was conducted during the Kharif season of 2024 at the Agriculture Research Farm, Vivekananda Global University, Jaipur. The soil of the experimental field was characterized as loamy sand in texture, slightly alkaline in reaction with an EC in the safe range, low in organic carbon and nitrogen, but possessing medium phosphorus and potassium levels. The experiment was structured as a Randomized Block Design with three replications, encompassing nine distinct treatments: (T1) 100 % RDF, (T2) 75 % RDF + 3.5 tha Vermicompost, (T3) 75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter at 600 gha, (T4) 75 % RDF + 3.5 tha Vermicompost + seed treatment with PSB at 600 gha, (T5) 75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each, (T6) 50 % RDF + 4.5 tha Vermicompost, (T7) 50 % RDF + 4.5 tha Vermicompost + seed treatment with Azotobacter at 600 gha, (T8) 50 % RDF + 4.5 tha Vermicompost + seed treatment with PSB at 600 gha and (T9) 50 % RDF + 4.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each. Pioneer 86M82, a variety of pearl millet, served as the test crop. Results indicated that the maximum growth parameters, yield attributes, and yield were achieved with Treatment T5 (75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each). The, grain and stover yields for this treatment were 2947.44 kg ha^{-1} and 6871.67 kg ha^{-1}, respectively. Among all treatments, Treatment T5 also showed the highest net return (Rs. 61591.93 kg ha^{-1}) and B:C ratio (1.4).

Keywords: Pearl millet (Pennisetum glaucum L.), Integrated nutrient management, Vermicompost, Biofertilizers (Azotobacter and PSB), Randomized Block Design (RBD).

Introduction

Pearl millet (*Pennisetum glaucum* L.) is one of the most important coarse cereals cultivated in arid and semi-arid regions of India. It occupies nearly 7–8 million hectares annually, contributing significantly to food and fodder security in resource-poor farming systems [1]. It is well adapted to drought, high temperatures, and low-fertility soils, making it a strategic crop for climate-resilient agriculture. Pearl millet grains are rich in energy, iron, calcium, and dietary fiber, while the stover serves as a major source of fodder for livestock [2].

Despite its resilience, pearl millet productivity remains lower compared to its genetic potential, primarily due to poor soil fertility and imbalanced fertilizer use. Farmers traditionally apply nitrogen and phosphorus fertilizers in suboptimal amounts, while the role of potassium, organic manures, and biofertilizers is often neglected [3, 4]. Overreliance on chemical fertilizers alone has led to declining soil health and nutrient use efficiency, calling for sustainable nutrient management strategies [5].

Integrated nutrient management (INM), which combines inorganic fertilizers, organic manures, and biofertilizers, has emerged as a sustainable approach to improve soil fertility, crop growth, and yield [6]. Vermicompost, a nutrient-rich organic amendment, not only supplies macro- and micro-nutrients but also enhances soil microbial activity and structure [7]. Biofertilizers such as Azotobacter and phosphate-solubilizing bacteria (PSB) further contribute to nutrient availability by fixing atmospheric nitrogen and solubilizing insoluble forms of phosphorus, respectively [8, 9].

Several studies have demonstrated the beneficial effects of INM practices on cereals, including maize, wheat, and sorghum [10–13]. However, comprehensive data on pearl millet integrating vermicompost and biofertilizers with different fertility levels under semi-arid conditions are still limited. Addressing this knowledge gap is critical for formulating eco-friendly and cost-effective nutrient management strategies for pearl millet.

Materials and Methods

The field experiment was carried out during the Kharif season of 2024 at the Agricultural Research Farm of Vivekananda Global University, Jaipur, situated in semi-arid agro-climatic zone III A of Rajasthan. The region experiences wide temperature fluctuations (up to 48 °C in summer and down to 1 °C in winter) with most rainfall (450–

550 mm annually) occurring during the southwest monsoon in July–August. Throughout the pearl millet growing period, daily maximum temperatures ranged from 30.2 to 40.9 °C, minimums from 14.3 to 25.4 °C, relative humidity varied widely (15–85%), and sunshine hours ranged from 1.8 to 9.3 per day. A diverse cropping history preceded the trial, including sorghum, guar, chickpea, wheat, and mung, with pearl millet being the crop for 2024–25. Pre-sowing soil analysis (0–30 cm depth) revealed loamy sand texture, alkaline reaction (pH ~7), low organic carbon (0.23%), nitrogen (122.3 kg ha^{-1}) and phosphorus (16.44 kg ha^{-1}), but medium potassium (152.24 kg ha^{-1}). The experiment followed a randomized block design with three replications and nine treatments combining different levels of recommended dose of fertilizers (RDF), vermicompost, and biofertilizers (Azotobacter, PSB). Treatments ranged from 100% RDF to reduced RDF (75% or 50%) supplemented with vermicompost (3.5–4.5 tha) andor seed treatments with biofertilizers (600 gha). Pearl millet (variety MPMH-17) was sown at 4 kg ha^{-1} with 45 × 15 cm spacing. Vermicompost was applied 15 days before sowing; fertilizers were applied as basal (half N plus full P and K) and the remaining N at 30 DAS. Seeds were inoculated using a jaggery-based solution and shade dried before sowing. Cultural practices included ploughing, harrowing, thinning, weeding, and one lifesaving irrigation during moisture stress. Harvesting occurred on 7 October 2024 from a net plot of 21.6 m², followed by manual threshing and winnowing. Growth parameters (plant height, dry matter, chlorophyll), yield components (tillers, ear dimensions, test weight, grain weight), yields (grain, stover, biological yield), nutrient content (N, P, K), protein content (based on nitrogen × 6.25), protein yield, and economics (cost, grossnet returns, B:C ratio) were recorded. Data were statistically analyzed using ANOVA and critical difference at p = 0.05 following Cochran & Cox (1963) methodology.

Table 1 Impact of fertility levels, vermicompost and bio-fertilizers on economics on yield attributes and yield of pearl millet.

Sr. No.	Treatment	Plant height (cm)				Dry matter accumulation (cm)				Chlorophyll content (mg g_{-1}) at 65 DAS
		At 25 DAS	At 45 DAS	At 65 DAS	At harvest	At 25 DAS	At 45 DAS	At 65 DAS	At harvest	
T1	100 % RDF	25.67	62.68	131.43	172	54.93	135.16	558.68	764	2.791
T2	75 % RDF + 3.5 tha Vermicompost	28.67	58.64	122.32	188	63	132.68	591.86	863.53	2.86
T3	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter at 600 gha	31.4	61.3	142.13	194	66.67	144.23	681.37	934.38	2.942
T4	75 % RDF + 3.5 tha Vermicompost + seed treatment with PSB at 600 gha	29.33	64.24	139.33	195.62	63.39	139.6	651.17	900.23	2.999
T5	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	38.67	68.68	144.53	197.35	68.43	146.22	690.66	957	3.097
T6	50 % RDF + 4.5 tha vermicompost	25.33	56.38	115	176.57	58.23	113.34	574.22	771.44	2.75
T7	50 % RDF + 4.5 tha vermicompost + seed treatment with Azotobacter at 600 gha	33.5	65.45	132.67	184.69	64	131.67	622.36	880.42	2.917
T8	50 % RDF + 4.5 tha Vermicompost + seed treatment with PSB at 600 gha	30.4	64.32	134.69	173.61	63	125.79	609.23	797.27	2.79
T9	50 % RDF + 4.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	34.7	68.23	143.68	194.57	68	144.87	684.69	934.32	3.0987
	C.D.	1.344	2.323	6.99	6.64	2.436	5.783	25.916	37.282	0.142
	SE(m)	0.444	0.768	2.312	2.196	0.805	1.912	8.571	12.329	0.047

In this study, soil nutrient analysis was carried out using standard chemical methods: available nitrogen was estimated by the alkaline $KMnO_4$ method, phosphorus by Olsen's method, and potassium by the flame photometer after neutral ammonium acetate extraction. Nutrient content in plant samples (N, P, K) was determined after digestion, with nitrogen estimated by the Kjeldahl method, phosphorus colorimetrically, and potassium using a flame photometer. Chlorophyll content in leaves was measured following Arnon's method (1949), which involves acetone extraction and spectrophotometric readings, providing a reliable estimate of total chlorophyll concentration. These analytical approaches ensured precise evaluation of nutrient status and chlorophyll levels to interpret treatment effects on pearl millet growth and productivity.

Table 2 Impact of fertility levels, vermicompost and bio-fertilizers on economics on yield attributes and yield of pearl millet

Sr. No.	**Treatment**	**Yield attributes**					**Yield (kg ha^{-1})**			
		Number of effective tillers per plant	**Length of ear head (cm)**	**Girth of ear head (cm)**	**Grain weight per ear head (g)**	**Test weight (g)**	**Grain yield**	**Stover yield**	**Biological yield**	**Harvest index**
T1	100 % RDF	1.1	26.55	9.32	4.91	7.35	2122.23	4848.87	6971.1	30.44
T2	75 % RDF + 3.5 tha Vermicompost	1.4	27.44	9.57	5.35	6.96	2490.13	5824	8314.13	29.95
T3	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter at 600 gha	1.5	29.16	9.68	5.86	7.81	2579.22	6503	9082.22	28.39
T4	75 % RDF + 3.5 tha Vermicompost + seed treatment with PSB at 600 gha	1.6	29.23	9.61	5.94	7.45	2747.63	6197	8944.63	30.71
T5	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	1.97	31.32	9.87	6.67	8.23	2947.44	6871.67	9819.11	30.01
T6	50 % RDF + 4.5 tha vermicompost	1.84	27.23	9.53	5.07	6.99	2200.43	4918	7118.43	30.91
T7	50 % RDF + 4.5 tha vermicompost + seed treatment with Azotobacter at 600 gha	1.85	29.13	9.55	5.72	7.67	2597	6102	8699	29.85
T8	50 % RDF + 4.5 tha Vermicompost + seed treatment with PSB at 600 gha	1.87	28.17	9.49	5.87	7.57	2290.67	5367	7657.67	29.91
T9	50 % RDF + 4.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	1.94	30.16	9.86	6.47	8.13	2894	6722.33	9616.33	30.094
	SEm ±	0.05	1.242	0.326	0.176	0.383	105.39	363.0	307.69	1.134
	CD (P=0.05)	0.016	0.411	0.108	0.058	0.127	34.85	120.04	101.75	0.375

Results and Discussion

Plant height increased consistently across treatments, with maximum height (197.35 cm) recorded in T5 (75% RDF + Vermicompost + Azotobacter + PSB), significantly higher than sole RDF (T1: 172 cm). This can be attributed to synergistic effects of inorganic and organic nutrient sources that enhanced nutrient uptake and physiological growth [14]. Similar trends were observed for dry matter accumulation, with T5 producing 957 gplant at harvest, reflecting better assimilation of photosynthates. Chlorophyll content at 65 DAS was also highest in T5 (3.097 mg g^{-1}), confirming the role of biofertilizers in improving nitrogen metabolism [15].

Yield attributes such as effective tillers (1.97), ear head length (31.32 cm), and test weight (8.23 g) were highest under T5, closely followed by T9 (50% RDF + vermicompost + Azotobacter + PSB). Grain yield was significantly influenced, ranging from 2122 kg ha^{-1} (T1) to 2947 kg ha^{-1} (T5). This represented a 38.9% increase over RDF alone. Enhanced yield under INM treatments could be linked to improved root growth, nutrient availability, and soil microbial activity [16, 17].

Stover yield also followed a similar trend, with maximum yield under T5 (6871.67 kg ha^{-1}). Harvest index remained within 28–31%, indicating balanced partitioning between grain and biomass. These findings corroborate earlier reports where integrated nutrient sources improved productivity in pearl millet and sorghum [18, 19].

Economic analysis revealed that T5 registered the highest gross returns (Rs. 99,202ha), net returns (Rs. 61,591ha), and B\:C ratio (1.64). Sole RDF treatment (T1) recorded lower profitability with a B\:C ratio of 1.12, while treatments with 50% RDF + vermicompost alone (T6) were uneconomical (B\:C ratio 0.92). The superior profitability of T5 was due to higher yields and better price realization. These results align with reports suggesting that partial substitution of RDF with vermicompost and biofertilizers is not only sustainable but also economically viable [20, 21].

Table 3 Impact of fertility levels, vermicompost and bio-fertilizers on economics in of pearl millet

S. No.	Treatments	Cost of cultivation (Rs. ha)	Gross returns (Rs. ha)	Net returns (Rs. ha)	B: C
T1	100 % RDF	33395	70933.41	37538.4	1.12
T2	75 % RDF + 3.5 tha Vermicompost	34275	83902.86	49627.8	1.45
T3	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter at 600 gha	35375	89257.84	53882.8	1.53
T4	75 % RDF + 3.5 tha Vermicompost + seed treatment with PSB at 600 gha	36000.45	91432.86	55432.4	1.54
T5	75 % RDF + 3.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	37610.1	99202.03	61591.9	1.64
T6	50 % RDF + 4.5 tha vermicompost	37944.72	72999.46	35054.7	0.92
T7	50 % RDF + 4.5 tha vermicompost + seed treatment with Azotobacter at 600 gha	36224.94	87644	51419.0	1.45
T8	50 % RDF + 4.5 tha Vermicompost + seed treatment with PSB at 600 gha	37475.1	81629.74	44154.6	1.17
T9	50 % RDF + 4.5 tha Vermicompost + seed treatment with Azotobacter + PSB at 600 gha each	37941.57	97279.65	59338.0	1.56
	C.D.	1,663.15	3,984.89	2,270.54	0.058
	SE(m)	550.016	1,317.84	750.887	0.019

Conclusion

The present study demonstrated that integrated nutrient management significantly enhanced growth, yield attributes, grain yield, and economics of pearl millet. Application of 75% RDF + 3.5 tha vermicompost + seed treatment with Azotobacter and PSB (T5) proved most effective, recording the highest grain yield (2947 kg ha^{-1}), stover yield (6871 kg ha^{-1}), and net returns (Rs. 61,591ha). Thus, 25% saving in chemical fertilizers is possible without compromising yield, provided vermicompost and biofertilizers are used synergistically. Adoption of INM practices can improve soil fertility, crop productivity, and farm profitability, making pearl millet cultivation more sustainable in semi-arid regions.

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