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Effect of integrated nutrient management and seed bio-priming on root parameters, harvest index and nutrient use efficiency of lentil crop on alluvial soil of Ballia

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Abstract

A field study was carried out during the Rabi seasons of 2021 and 2023 at the Agricultural Research Farm of Shri Murli Manohar Town Post Graduate College, Ballia, Uttar Pradesh, to assess the impact of integrated nutrient management and seed bio-priming on the growth, yield, quality of lentil (*Lens culinaris* M.), and fertility status of alluvial soil. The experiment consisted of eleven treatment combinations involving different levels of recommended NPK fertilizers, organic inputs such as vermicompost, press mud, and fly ash, seed bio-priming with Rhizobium and phosphate-solubilizing bacteria (PSB), and foliar application of boron at concentrations of 0.2% and 0.5% applied at the flowering stage, arranged in a randomized block design. Various growth and yield parameters, namely seedling dry matter accumulation, plant height, number of primary and secondary branches, number of leaves and pods per plant, grain yield, stover yield, and total biological yield, were recorded at 90 days after sowing (DAS). The findings revealed that the combined application of 75% of the recommended NPK dose along with organic amendments, seed bio-priming, and boron foliar spray resulted in a significant improvement in plant growth, yield components, and seed yield over the control as well as treatments receiving only chemical fertilizers. Among the treatments, the application of vermicompost in conjunction with bio-priming and boron spray produced the most favorable results, suggesting improved nutrient availability and enhanced soil fertility status. Overall, the integration of nutrient management practices with seed bio-priming and boron application was found to be an effective strategy for enhancing productivity and sustainability of lentil cultivation under alluvial soil conditions of eastern Uttar Pradesh.

Keywords: Integrated nutrient management, Seed bio-priming, Lentil (*Lens culinaris* M.), Vermicompost, Rhizobium, Phosphate-solubilizing bacteria (PSB), Boron foliar application, Alluvial soil, Yield attributes, Soil fertility

Introduction

Lentil (*Lens culinaris* M.) belongs to the family Leguminosae and is categorized as an important pulse crop cultivated during the Rabi season. It is one of the oldest and most nutritious food legumes, well known for its ability to tolerate cold climatic conditions, including frost. The crop requires cool temperatures during the vegetative growth phase and moderately warm conditions (18-30°C) at the time of maturity. Lentil also exhibits high adaptability to moisture-deficient soils, as it requires comparatively less irrigation and shows greater tolerance to drought stress than many other crops (Sehgal *et al.*, 2021) ^[2].

In India, lentil is commonly known as “masoor” and is often referred to as “the poor man’s meat” because of its high nutritional value. The seeds are rich in dietary fiber, carbohydrates, vitamins A and B, potassium, and iron, while containing low levels of fat and salt. Lentils are mainly consumed in the form of dry seeds and constitute an important component of the human diet. Owing to their nutritional richness, lentils rank among the most significant edible grain legumes contributing to a balanced and healthy diet.

Dry lentil seeds are rich in several essential minerals, typically containing 65 g of total carbohydrates, 20 g of protein, 4 g of fiber, and 0.6 g of fat per 100 g. Compositional ranges, as gathered by Grusak (2009) ^[7] from various studies, include ash (2.2-6.4%), total fiber (5.1% to 26.6%), fat (0.3% to 3.5%) protein (15.9% to 31.4%), and carbs (43.4% to 74.9%). Due to its

cost-effectiveness as a protein source (21-31%), lentils are often referred to as the "poor man's meat," offering valuable nutrition for those in underdeveloped nations, individuals with limited financial resources, vegetarians, and vegans (Argel *et al.*, 2020, Dhull *et al.*, 2023) ^[5, 6]. Lentil proteins are rich in leucine, arginine, glutamic acid, and aspartic acid, encompassing all nine necessary amino acids (39.3 g per 100 g of proteins). Additionally, lentils are high in lysine, enhancing the amino acid profile of cereal grains. However, they are deficient in tryptophan and sulfur-containing amino acids such as methionine and cysteine (Romano *et al.*, 2021; Sa *et al.*, 2023) ^[4]. Compared to common cereal grains, lentils, being high in proteins and low in carbohydrates, provide nutrient-dense alternatives for consumers seeking meat alternatives.

With a 44% and 18% share of global production, respectively, Canada dominates global lentil production, followed closely by India (Food and Agriculture Organization, 2021) ^[11]. The data from 2021-22 reveals that Rajasthan holds the top position as the leading pulse producer in India, boasting an annual production of 4364.74 tonnes. Projections for the financial year 2023 estimate India's lentil production during the Rabi season to exceed 1.6 million metric tons (Sandhya Keelery, 2023) ^[1]. Integrated nutrient management had significant effects on the plant height, number of branches per plant, number of pods per plant, number of seeds pod⁻¹, 1000-seed weight, and seed yield of lentil. The maximum seed yield (1216 kg ha⁻¹) as well as protein content (26.1%) were recorded (Aktar *et al.*, 2019) ^[12].

Bio-priming of seed is a wonderful approach to meet the demand of chemical free food for ever increasing population. Bio-priming of seed uses microbial inoculants of plant growth promoting rhizobacteria and fungi. It is an eco-friendly strategy using selected microorganism which produces substances for growth promotion and pathogen inhibition. Presently, seed treatment with biological inoculants is being used as a substitute to synthetic chemical pesticides and fertilizers in agriculture for plant and soil health improvement. Using biocontrol agents with priming agents for seed treatment over simple seed coating has potential advantages and serves as a better strategy of managing many seed and soil-borne diseases. Essential nutrients are vital for plant growth and sustainable agriculture. They improve nutrition in human beings. There is a global concern for either less or excessive use of nutrients in soils. To address this issue, indicators like nutrient use efficiency (NUE) have been developed. Anthropogenic sources are major causes for greenhouse gases (GHG) emissions and global warming. We are losing 60-80% N and 30-75% P in the environment leading to degradation of soil quality and continuous reduction in soil fertility.

Keeping these concerns, the United Nations is celebrating this decade (2021-2030) as United Nations Decade on Ecosystem Restoration (UNDESR).

Acquisition efficiency and utilization efficiency both govern the efficient use of nutrients. A higher harvest index (HI) is an indicator of a higher NUE. The incorporation of dwarf genes in wheat and rice improved the HI and NUE of the plant (Ellis *et al.*, 2005) ^[13].

In this study, our main objective was to contribute to the sustainable agricultural production of our region in particular, and our country in general, with practices that are more protective of human health than chemical fertilizer applications, by capturing the benefits of organic fertilization in our region.

Material and Methods

Experimental Site

The field experiments were conducted during the Rabi seasons of 2021-2022 and 2022-2023 at the Nidharia Agricultural Research Farm, Shri Murli Manohar Town PG College, Ballia, Uttar Pradesh, India (affiliated to Jananayak Chandrasekhar University, Ballia). The farm is situated at 25°0.76' N latitude, 84°0.12' E longitude, and 59 m above sea level, in the easternmost part of Uttar Pradesh, bordering Bihar. The district is part of the central plain zone with a sub-tropical climate, characterized by an average annual temperature of 25°C, maximum temperatures reaching 44°C during peak summer, and minimum temperatures dropping to 0°C during winter. The average annual rainfall is 648 mm, mostly received during July-September, with occasional light winter showers.

Experimental Soil

Soil Sampling and Characterization

Composite soil samples were collected from the 0-15 cm layer of the experimental field before sowing. Samples were analyzed for physical, physico-chemical, chemical, and biological properties, as well as carbon fractions, in the Department of Agricultural Chemistry and Soil Science, S. M. M. Town PG College, Ballia.

Plant Material

The lentil variety L-4717 (Pusa) was used. It is a short-duration crop maturing in 90-110 days with an average productivity of 13-17 q ha⁻¹. Seeds were sown at 30 kg ha⁻¹, with row spacing of 30 cm and plant spacing of 10 cm. Seeds were sown manually at 3-5 cm depth.

Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with 11 treatment combinations, each replicated three times. Each plot measured 3 m × 5 m with 1 m wide main irrigation channel and 75 cm sub-channels.

Treatment Combinations

Symbol	Treatment
T ₁	Control (No fertilizer or bio-priming)
T ₂	100% RDF (N20:P40:K20 kg ha ⁻¹)
T ₃	75% RDF + 5 t vermicompost ha ⁻¹
T ₄	75% RDF + 5 t press mud ha ⁻¹
T ₅	75% RDF + 5 t fly ash ha ⁻¹
T ₆	T ₃ + Seed bio-priming with PGPR + 0.2% B spray at flowering
T ₇	T ₄ + Seed bio-priming with PGPR + 0.2% B spray at flowering
T ₈	T ₅ + Seed bio-priming with PGPR + 0.2% B spray at flowering
T ₉	T ₃ + Seed bio-priming with PGPR + 0.5% B spray at flowering
T ₁₀	T ₄ + Seed bio-priming with PGPR + 0.5% B spray at flowering
T ₁₁	T ₅ + Seed bio-priming with PGPR + 0.5% B spray at flowering

Note: Seed bio-priming involved Rhizobium culture (10 g kg⁻¹ seed) and PSB culture (10 g kg⁻¹ seed), applied 24 hours before sowing to improve germination and nodulation.

Fertilizer and Organic Manure Application

Organic manures (vermicompost, press mud, fly ash) and inorganic fertilizers (urea, SSP, MOP) were applied 3 days before sowing as per treatment schedule. The nutrient composition of manures and fertilizers was analyzed prior to application.

Crop Management: Soil Treatment: Trichoderma powder at 2.47 kg ha⁻¹ was applied for fungal disease protection. Interculture Operations: Two hand weeding operations at 20 and 45 DAS.

Tagging Plants: Five plants per plot were randomly tagged for growth and yield observations. Irrigation: Applied only when necessary.

Observations Recorded

Root Parameters

- **Root length:** Measured at 90 DAS on 5 tagged plants plot-1.
- Shoot Length
- **Root:** Shoot Ratio Per Plant
- Root Volume Per Lants
- **Harvest Index (HI):** HI = Grain yield / Biological yield × 100.

Nutrient Use Efficiency

- **Agronomic Efficiency (AE):** AE = (Y-Y₀)/F
- **Physiological Efficiency (PE):** PE = (Y-Y₀)/(U-U₀)
- **Apparent Recovery Efficiency (ARE):** ARE = ((U-U₀)/F) × 100
- Particle Factor Productivity (PFP): PFP= Y/F

Result and Discussion

Root Parameters: Root Length: Root length of lentil recorded at 90 days after sowing (DAS) was significantly influenced by different integrated nutrient management treatments (Table 1). Root length increased progressively with crop age under all treatments. at 90 DAS (14.02cm) was observed under the treatment 75% recommended NPK combined with organic amendments, seed bio-priming, and boron application (T₉)

whereas the minimum (14.02cm and 14.39 cm) was recorded under control (T₁). The improvement in root length under integrated treatments may be attributed to enhanced soil structure, microbial activity, and balanced nutrient availability.

Shoot Length

Shoot length showed a significant increase with advancement in crop growth and varied markedly among treatments (Table 1). Treatments receiving integrated application of inorganic fertilizers along with vermicompost, bio-priming, and boron spray (T₉) recorded significantly higher shoot length (37.31cm and 38.29cm) compared to sole fertilizer and control treatments (27.82 cm and 27.62 cm) (T₁). Improved shoot growth under integrated nutrient management may be due to better nutrient uptake and enhanced physiological activity.

Root: Shoot Ratio per Plant

The root: shoot ratio per plant was significantly affected by different nutrient management practices (Table 1). Higher root:shoot ratios (0.376 and 0.376) were observed in treatments involving organic amendments and seed bio-priming (T₉) indicating better root development relative to shoot growth. Lower ratios (0.354 and 0.327) were recorded under control and sole chemical fertilizer treatments. The balanced nutrient supply under integrated treatments may have promoted efficient assimilate partitioning.

Root Volume per Plant

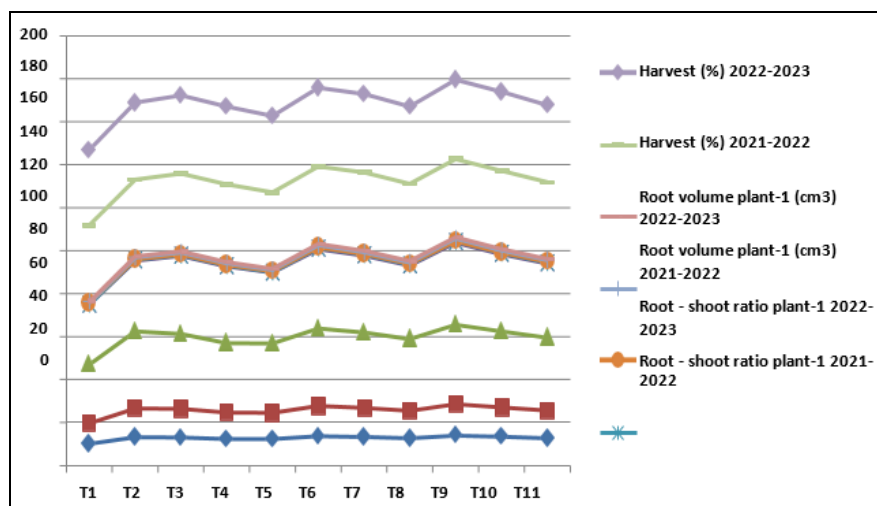
Root volume per plant varied significantly among treatments (Table 1). The highest root volume (0.69 and 0.73cm³) was recorded in treatments receiving vermicompost in combination with bio- priming and boron spray (T₉) while the lowest (0.42 and 0.44 cm³) was observed under control (T₁). Increased root volume under integrated treatments suggests improved root proliferation, which enhances nutrient and water absorption.

Harvest Index (HI)

Harvest index (HI) was significantly influenced by different treatments (Table 1). Higher HI values (36.63% and 36.71%) were recorded under integrated nutrient management treatments, reflecting efficient translocation of assimilates towards grain yield (T₉). In contrast, the lowest HI (35.21 and 35.13%) was observed under control (T₁) indicating poor biomass conversion efficiency. Similar trends have been reported under integrated nutrient management practices in pulse crops.

Table 1: Effect of integrated nutrient management and seed bio-priming on growth parameters and harvest index

Treatment	Root length (cm)		Shoot length plant ⁻¹ (cm)		Root - shoot ratio plant ⁻¹		Root volume plant ⁻¹ (cm ³)		Harvest (%)	
	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023
T ₁	9.84	9.69	27.82	27.62	0.354	0.327	0.42	0.44	35.21	35.13
T ₂	13.13	13.25	36.19	32.85	0.363	0.364	0.59	0.61	35.71	35.73
T ₃	12.99	13.22	35.21	36.23	0.369	0.365	0.60	0.65	36.23	36.28
T ₄	12.17	12.22	32.79	35.57	0.371	0.353	0.62	0.60	36.10	36.13
T ₅	12.15	12.19	32.65	32.81	0.372	0.371	0.54	0.55	35.46	35.49
T ₆	13.66	13.83	36.49	36.94	0.374	0.375	0.66	0.68	36.25	36.50
T ₇	13.22	13.40	35.52	35.70	0.372	0.372	0.63	0.65	36.49	36.47
T ₈	12.60	12.63	33.80	34.15	0.373	0.37	0.63	0.64	35.84	35.90
T ₉	14.02	14.39	37.31	38.29	0.376	0.376	0.69	0.73	36.63	36.71
T ₁₀	13.37	13.43	35.82	35.90	0.373	0.374	0.67	0.68	36.60	36.68
T ₁₁	12.62	12.72	34.39	34.40	0.367	0.37	0.65	0.66	35.68	35.82
SEm±	0.02	0.01	0.02	0.03	0.01	0.01	0.03	0.03	0.11	0.11
CD (P=0.05)	0.07	0.03	0.05	0.10	0.02	0.02	0.08	0.08	0.31	0.32



Graph 1: Effect of integrated nutrient management and seed bio-priming on growth parameters and harvest index

Nutrient Use Efficiency

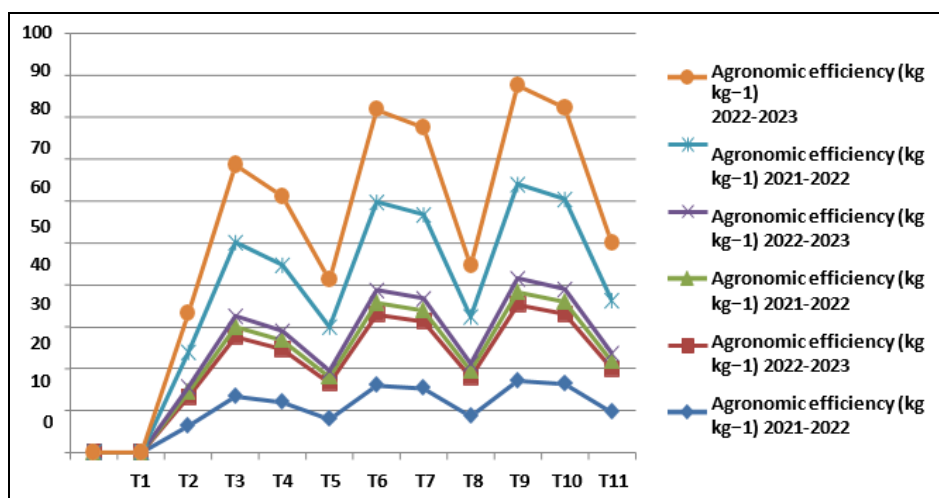
Agronomic Efficiency (AE)

Agronomic efficiency varied significantly among treatments (Table 02). The highest AE (kg grain kg⁻¹ nutrient applied) was recorded under treatments receiving reduced chemical fertilizer

doses combined with organic amendments, bio-priming, and boron application (T₉). Lower AE values were observed under sole fertilizer treatments (T₂). Higher AE under integrated treatments indicates better yield response per unit of nutrient applied.

Table 2: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (agronomic efficiency)

Treatment	Agronomic Efficiency (kg kg ⁻¹)	2021-2022 (Nitrogen)	2022-2023 (Nitrogen)	2021-2022 (Phosphorus)	2022-2023 (Phosphorus)	2021-2022 (Potassium)	2022-2023 (Potassium)
T ₁	Control	0.00	0.00	0.00	0.00	0.00	0.00
T ₂	100% RDF (N20:P40:K20 kg ha ⁻¹)	6.32	6.94	1.10	1.21	8.27	9.37
T ₃	75% RDF + 5 t vermicompost ha ⁻¹	13.40	14.30	2.33	2.48	17.60	18.60
T ₄	75% RDF + 5 t press mud ha ⁻¹	12.00	12.70	2.08	2.21	15.70	16.60
T ₅	75% RDF + 5 t fly ash ha ⁻¹	7.95	8.66	1.38	1.50	10.40	11.30
T ₆	T ₃ + Seed bio-priming with PGPR + 0.2% B spray at flowering	16.00	17.00	2.79	2.95	21.00	22.20
T ₇	T ₄ + Seed bio-priming with PGPR + 0.2% B spray at flowering	15.30	16.00	2.66	2.78	20.00	21.00
T ₈	T ₅ + Seed bio-priming with PGPR + 0.2% B spray at flowering	8.60	9.43	1.49	1.64	11.20	12.30
T ₉	T ₃ + Seed bio-priming with PGPR + 0.5% B spray at flowering	17.20	18.20	2.98	3.16	22.50	23.80
T ₁₀	T ₄ + Seed bio-priming with PGPR + 0.5% B spray at flowering	16.40	16.80	2.85	2.92	21.50	22.00
T ₁₁	T ₅ + Seed bio-priming with PGPR + 0.5% B spray at flowering	9.61	10.50	1.67	1.83	12.60	13.80
SEm±	Standard Error of the Mean	0.13	0.13	0.02	0.02	0.17	0.17
CD(P=0.05)	Critical Difference at P=0.05	0.39	0.38	0.07	0.07	0.51	0.50



Graph 2: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (agronomic efficiency)

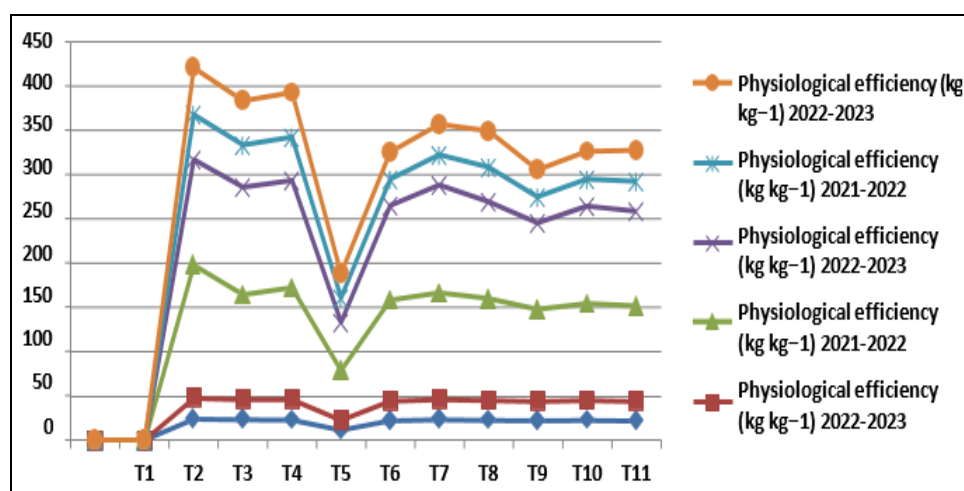
Physiological Efficiency (PE)

Physiological efficiency also differed significantly among treatments (Table 03). The maximum PE (kg grain kg⁻¹ nutrient uptake) was recorded under integrated nutrient management

treatments (T₂), suggesting efficient conversion of absorbed nutrients into economic yield. The lowest PE was observed in control plots (T₅), possibly due to nutrient stress and poor metabolic efficiency.

Table 3: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (physiological efficiency)

Treatment	Physiological Efficiency (kg kg ⁻¹)	2021-2022 (Nitrogen)	2022-2023 (Nitrogen)	2021-2022 (Phosphorus)	2022-2023 (Phosphorus)	2021-2022 (Potassium)	2022-2023 (Potassium)
T ₁	Control	0.00	0.00	0.00	0.00	0.00	0.00
T ₂	100% RDF (N20:P40:K20 kg ha ⁻¹)	24.29	24.09	148.35	119.34	51.19	51.88
T ₃	75% RDF + 5 t vermicompost ha ⁻¹	23.40	23.13	116.84	121.51	48.01	49.01
T ₄	75% RDF + 5 t press mud ha ⁻¹	23.24	23.22	124.53	121.55	49.26	49.57
T ₅	75% RDF + 5 t fly ash ha ⁻¹	11.13	11.45	55.59	54.49	27.61	27.29
T ₆	T ₃ + Seed bio-priming with PGPR + 0.2% B spray at flowering	22.47	22.47	112.29	106.90	29.98	29.95
T ₇	T ₄ + Seed bio-priming with PGPR + 0.2% B spray at flowering	23.25	23.27	118.94	122.17	33.93	34.17
T ₈	T ₅ + Seed bio-priming with PGPR + 0.2% B spray at flowering	22.77	22.70	113.51	109.70	39.02	40.30
T ₉	T ₃ + Seed bio-priming with PGPR + 0.5% B spray at flowering	22.34	22.14	102.36	97.68	29.79	30.06
T ₁₀	T ₄ + Seed bio-priming with PGPR + 0.5% B spray at flowering	22.82	22.90	107.46	110.44	30.61	30.56
T ₁₁	T ₅ + Seed bio-priming with PGPR + 0.5% B spray at flowering	22.11	22.51	106.10	107.01	34.16	34.38
	SEm±	0.17	0.16	13.09	3.25	1.13	1.08
CD(P=0.05)	Critical Difference at P=0.05	0.49	0.48	38.61	9.59	3.34	3.18



Graph 3: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (physiological efficiency)

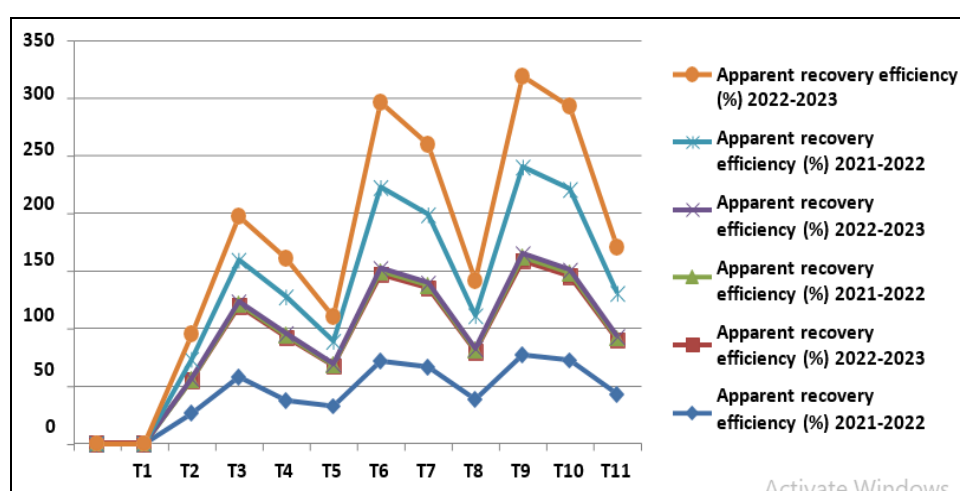
Apparent recovery efficiency showed significant variation due to different nutrient management practices (Table 04). Higher ARE values were observed under treatments involving organic amendments and bio-fertilizers along with inorganic fertilizers

(T₉) indicating improved nutrient uptake efficiency. The lowest ARE was recorded under control (T₂). Enhanced nutrient recovery under integrated treatments may be attributed to improved root growth and microbial activity.

Table 4: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (apparent recovery efficiency)

Treatment	Apparent Recovery Efficiency (%)	2021-2022 (Nitrogen)	2022-2023 (Nitrogen)	2021-2022 (Phosphorus)	2022-2023 (Phosphorus)	2021-2022 (Potassium)	2022-2023 (Potassium)
T ₁	Control	0.00	0.00	0.00	0.00	0.00	0.00
T ₂	100% RDF (N20:P40:K20 kg ha ⁻¹)	26.05	28.82	0.85	1.02	16.33	21.56

T ₃	75% RDF + 5 t vermicompost ha ⁻¹	57.41	61.67	2.00	2.04	35.90	38.06
T ₄	75% RDF + 5 t press mud ha ⁻¹	37.30	54.76	1.70	1.82	31.67	33.54
T ₅	75% RDF + 5 t fly ash ha ⁻¹	32.25	34.73	0.97	1.22	19.65	21.27
T ₆	T ₃ + Seed bio-priming with PGPR + 0.2% B spray at flowering	71.16	75.60	2.49	2.77	70.09	74.18
T ₇	T ₄ + Seed bio-priming with PGPR + 0.2% B spray at flowering	66.11	68.89	2.25	2.28	58.98	61.34
T ₈	T ₅ + Seed bio-priming with PGPR + 0.2% B spray at flowering	38.07	41.58	1.36	1.50	28.51	30.60
T ₉	T ₃ + Seed bio-priming with PGPR + 0.5% B spray at flowering	76.48	82.23	2.92	3.24	74.96	79.19
T ₁₀	T ₄ + Seed bio-priming with PGPR + 0.5% B spray at flowering	71.99	73.34	2.66	2.64	69.94	71.88
T ₁₁	T ₅ + Seed bio-priming with PGPR + 0.5% B spray at flowering	42.88	46.82	1.58	1.71	37.50	40.08
SEm±	Standard Error of the Mean	4.22	0.68	0.11	0.07	0.72	1.04
CD(P=0.05)	Critical Difference at P=0.05	12.45	2.01	0.32	0.21	2.11	3.07



Graph 4: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency (apparent recovery efficiency)

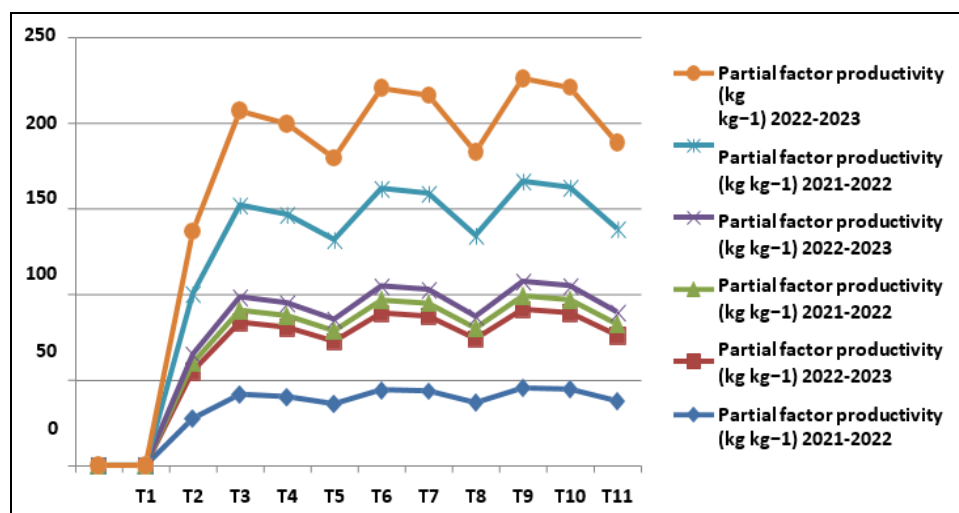
In the present study, partial factor productivity varied significantly among different nutrient management treatments (Table). Higher PFP values (kg kg⁻¹) were recorded under treatments receiving integrated application of inorganic fertilizers along with organic amendments, seed bio-priming, and boron spray, T₉ indicating improved utilization of applied nutrients. In contrast, lower PFP values (kg kg⁻¹) were observed under sole chemical fertilizer and control treatments T₂. The enhanced PFP under integrated nutrient management may be attributed to balanced nutrient supply, improved soil physical

properties, enhanced microbial activity, and better nutrient availability throughout the crop growth period. Organic amendments and bio-fertilizers improve nutrient synchronization with crop demand, thereby reducing nutrient losses and increasing fertilizer-use efficiency. Overall, the results suggest that partial factor productivity was maximized under integrated nutrient management practices, highlighting their role in achieving higher yields with reduced chemical fertilizer inputs and improved sustainability of lentil production.

Table 5: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency partial factor productivity

Treatment	Partial Factor Productivity (kg kg ⁻¹)	2021-2022 (Nitrogen)	2022-2023 (Nitrogen)	2021-2022 (Phosphorus)	2022-2023 (Phosphorus)	2021-2022 (Potassium)	2022-2023 (Potassium)
T ₁	Control	0.00	0.00	0.00	0.00	0.00	0.00
T ₂	100% RDF (N20:P40:K20 kg ha ⁻¹)	27.10	27.88	4.71	4.85	35.48	36.51
T ₃	75% RDF + 5 t vermicompost ha ⁻¹	41.18	42.23	7.15	7.33	53.83	55.20
T ₄	75% RDF + 5 t press mud ha ⁻¹	39.72	40.68	6.90	7.06	51.92	53.18
T ₅	75% RDF + 5 t fly ash ha ⁻¹	35.69	36.62	6.20	6.36	46.66	47.88
T ₆	T ₃ + Seed bio-priming with PGPR + 0.2% B spray at flowering	43.79	44.96	7.60	7.80	57.24	58.77
T ₇	T ₄ + Seed bio-priming with PGPR + 0.2% B spray at flowering	43.08	43.99	7.48	7.64	56.32	57.51
T ₈	T ₅ + Seed bio-priming with PGPR + 0.2% B spray at flowering	36.35	37.39	6.31	6.49	47.52	48.88

T ₉	T ₃ + Seed bio-priming with PGPR + 0.5% B spray at flowering	44.93	46.18	7.80	8.02	58.73	60.36
T ₁₀	T ₄ + Seed bio-priming with PGPR + 0.5% B spray at flowering	44.16	44.76	7.67	7.77	57.72	58.51
T ₁₁	T ₅ + Seed bio-priming with PGPR + 0.5% B spray at flowering	37.36	38.50	6.49	6.68	48.83	50.33
SEm±	Standard Error of the Mean	0.13	0.13	0.02	0.02	0.17	0.17
CD(P=0.05)	Critical Difference at P=0.05	0.39	0.38	0.07	0.07	0.51	0.50



Graph 5: Effect of integrated nutrient management and seed bio-priming on nutrient use efficiency partial factor productivity

Conclusion: Based on the findings of the present investigation conducted during the Rabi seasons of 2021 and 2023 under alluvial soil conditions of eastern Uttar Pradesh, it can be concluded that integrated nutrient management combined with seed bio-priming and boron application had a significant and positive influence on the growth, yield, harvest index, and nutrient use efficiency of lentil (*Lens culinaris* M.). The integrated application of 75% recommended NPK along with organic amendments, particularly vermicompost, seed bio-priming with *Rhizobium* and phosphate-solubilizing bacteria, and foliar application of boron resulted in superior performance in terms of root and shoot growth, root volume, root:shoot ratio, yield attributes, and seed yield compared to control and sole chemical fertilizer treatments. Improved harvest index and enhanced nutrient use efficiency parameters such as agronomic efficiency, physiological efficiency, apparent recovery efficiency, and partial factor productivity further indicated efficient utilization of applied nutrients under integrated treatments. The improved crop performance under integrated nutrient management may be attributed to balanced nutrient supply, enhanced microbial activity, improved soil physical and biological properties, and better nutrient uptake and utilization. Overall, the study highlights that integrated nutrient management coupled with seed bio-priming and boron supplementation is a sustainable and economically efficient approach for enhancing lentil productivity while maintaining soil fertility under alluvial soil conditions. Therefore, the adoption of integrated nutrient management practices with reduced chemical fertilizer input can be recommended for sustainable lentil cultivation in eastern Uttar Pradesh and similar agro-ecological regions.

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