



Phenology, Productivity and Profitability with Phosphate and Zinc Solubilizing Microbes in Lentil (*Lens culinaris* L.) under *tarai* region of Uttarakhand

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Abstract: The field experiment was conducted at G. B. Pant University of Agriculture and Technology, Pantnagar during *rabi* 2020 on phosphorus and zinc efficacy with phosphate and zinc solubilizing microbes in lentil (*Lens culinaris* L.) in *tarai* region. Twelve different doses of phosphorus and zinc with phosphate and zinc solubilizing microbes in combinations were evaluated. Growth parameters viz. plant height, number of branches per plant, number of compound leaves per plant and dry matter accumulation were highest with application of 50% RDP @ 24 kg ha⁻¹ + 12.5 kg ha⁻¹ ZnSO₄ + Biophos @ 5 ml kg⁻¹ seed + Biozinc @ 5 ml kg⁻¹ seed (40.5 cm, 14 no. plant⁻¹, 207 no. plant⁻¹, 8.2 g plant⁻¹, respectively) with respect to control (32.9 cm, 10.5 no. plant⁻¹, 136 no. plant⁻¹, 4.1 g plant⁻¹, respectively). Grain yield, harvest index, net returns and B: C ratio were also highest with the application of 50% RDP @ 24 kg ha⁻¹ + 12.5 kg ha⁻¹ ZnSO₄ + Biophos @ 5 ml kg⁻¹ seed + Biozinc @ 5 ml kg⁻¹ seed (1735 kg ha⁻¹, 0.53, 58460 ₹ ha⁻¹, 2.51, respectively) with respect to control (1318 kg ha⁻¹, 0.34, 40231 ₹ ha⁻¹, 1.82, respectively).

Keywords: Biophos, Biozinc, Harvest index, Nitrogen fixation, *Rhizobium*

Lentil (*Lens culinaris* L.) belongs to the family Fabaceae and about 5% of the total area under pulses is lentil of which Asia accounts for 65% in terms of production. In India, lentil is a significant pulse crop, grown on approximately 1.42 million hectares, yielding around 1.28 million tonnes (Sah et al 2022). The lentil crop accounts for about 4.9% of the total pulse cultivation area and contributes 5.03% to the country's overall pulse production (2021–22). Phosphorus and zinc are essential elements for successful plant growth, particularly in pulse production (Siddiqui et al 2015). Lentils use *Rhizobium* bacteria to fix atmospheric nitrogen, reducing the need for nitrogenous fertilizers to about 25-30 kg N ha⁻¹ (Singh and Singh 2016). Proper phosphorus application is essential for improving lentil yield and soil quality, although excess application can lead to fixation and unavailability in acidic or alkaline soils. Introducing phosphorus-solubilizing microbes (PSB) into the rhizosphere enhances phosphorus availability to plants through the release of organic acids and enzymes, potentially increasing crop yields by 10-30% and supplementing phosphorus needs. Zinc-solubilizing microorganisms use various mechanisms, such as acidification and chelation, to make zinc more available in the soil. Inoculating plants with beneficial bacteria like *Pseudomonas*, *Rhizobium* strains, *Bacillus* and *Azospirillum*

has shown improvements in growth, phosphorus and zinc content (Sindhu et al 2019, Chetan Babu et al 2023). Overall, these micronutrients and microbial interventions are crucial for optimizing crop health and yield in pulse production. The information available on the effect of phosphorus and zinc solubilizing microbes in the *Tarai* region of Uttarakhand is sparse and inadequate. With respect to this objective, the present study was conducted on phenology, productivity and profitability with phosphate and zinc solubilizing microbes in lentil.

MATERIAL AND METHODS

Experimental site: The field experiment was carried out during the *rabi* season of 2020 at N.E. Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology. The research center lies 30 km Southern end of foot hills of Shivalik Range of Himalayas at 29°N latitude and 79.3°E longitude and at an altitude of 243.83 m above the mean sea level in the *tarai* region of Uttarakhand.

Experiment details: The experiment was conducted with twelve treatments and three replications in randomized block design using lentil variety Pant L-8 with row to row spacing of 23cm and experimental area was about 812.16m² with gross plot size of 13.8m² (2.76 m x 5 m) each. The nutrients like N

and K were given to all treatments alike. But P, Zn and their solubilizing organisms were varied in different treatments. The other agronomic practices were followed as per the standard package of practices of lentil cultivation.

Growth and development parameters: At 30, 60, 90 days after sowing (DAS) and at harvest, the growth parameters were recorded. Height was measured from ground surface to the base of the apical leaf of five tagged plants from each plot. Total branch of branches of the five tagged plants were counted. The number of leaves from the five tagged plants were counted. Nodules collected from the five roots from of plants were dried in the oven at 70°C till the constant weight. Number of nodules were separated counted for the roots of five plants. The five plants were cut near the surface and dried in the hot air oven at 70°C till the constant weight.

Yield parameters: After threshing, the grain yield from each net plot was weighed and then multiplied with suitable conversion factor to get yield (kg ha⁻¹). Straw yield was calculated by deducting the grain yield from the biological yield. Total produce of each net plot (excluding the root biomass) was dried in the sun in the field after harvest and weighed. Yield ha⁻¹ was computed by multiplying this with suitable conversion factor.

$$\text{Harvest index} = (\text{grain yield} / \text{biological yield}) \times 100$$

Grain: Straw ratio was calculated by dividing the grain yield by straw yield.

Economic evaluation: Selling price of grain and straw were multiplied to the grain and straw yield to obtain the gross returns. The cost was deducted from the gross returns to obtain the net returns. The net return was divided by the cost of cultivation to obtain benefit cost (B: C) ratio.

Statistical analysis: The experimental data were analyzed using OPSTAT for randomized block design which is programmed by HAU, Hisar, Haryana.

RESULTS AND DISCUSSION

Growth and Development

Plant height (cm): Plant height increased up to crop maturity (Table 1). The rate of increase of plant height for 30-60 DAS, 60-90 DAS and 90 DAS to maturity stage was 0.19, 0.72 and 0.31 cm day⁻¹. Maximum increase was observed between 60-90 DAS stage. The T₁₀ produced tallest plants at 30, 60, 90 and maturity *i.e.* 6.4, 12.2, 32.9 and 40.5 cm, respectively and was significantly superior over the other treatments at 30, while at 60 DAS and 90 DAS, T₁₀, T₁₁ and T₁₂ were statistically on a par with each other, and significantly superior to other

Table 1. Plant height, number of branches and compound leaves at different stages of crop growth as influenced by phosphorous and zinc treatments

Treatments	Plant height (cm)				No. of branches plant ⁻¹				No. of compound leaves plant ⁻¹		
	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS	Maturity	30 DAS	60 DAS	90 DAS
T ₁ : Absolute Control (without P and Zn)	4.7	9.1	25.4	32.9	2.7	4.9	9.2	10.5	8.7	37	136
T ₂ : RDP (Control) @ 48 kg ha ⁻¹	5.2	10.9	28.6	37.9	2.9	6.3	11.3	12.4	9.2	43	146
T ₃ : Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	5.1	10.5	28.0	37.3	2.9	5.6	10.4	11.7	9.0	40	142
T ₄ : Biophos @ 5ml kg ⁻¹ seed	5.0	10.4	27.8	37.0	2.8	5.5	10.1	11.1	9.0	39	142
T ₅ : Biozinc @ 5ml kg ⁻¹ seed	4.9	9.8	26.5	35.1	2.8	5.3	9.6	10.8	8.8	37	137
T ₆ : Biophos and Biozinc @ 5 ml each kg ⁻¹ seed	5.2	10.7	28.5	37.6	2.9	5.8	10.8	11.8	9.1	42	145
T ₇ : 50% RDP @ 24 kg ha ⁻¹ + Biophos @ 5 ml kg ⁻¹ seed	5.2	11.1	29.1	38.1	3.0	6.4	11.6	12.4	9.8	43	158
T ₈ : 12.5 kg ha ⁻¹ ZnSO ₄ + Biozinc @ 5 ml kg ⁻¹ seed	5.0	10.1	27.7	36.4	2.8	5.5	9.6	11.1	8.9	39	139
T ₉ : 50% RDP @ 24 kg ha ⁻¹ + Biophos @ 5ml kg ⁻¹ seed + Biozinc @ 5 ml kg ⁻¹ seed	5.3	11.1	31.2	38.1	3.0	6.5	11.8	12.6	10.1	43	179
T ₁₀ : 50% RDP @ 24 kg ha ⁻¹ + 12.5 kg ha ⁻¹ ZnSO ₄ + Biophos @ 5 ml seed ⁻¹ + Biozinc @ 5 ml kg ⁻¹ seed	6.4	12.2	33.9	40.5	3.4	7.0	13.6	14.0	13.4	47	207
T ₁₁ : RDP @ 48 kg ha ⁻¹ + Nutrient Mobilizer (LNm 43a) @ 20 g kg ⁻¹ seed	5.7	11.3	32.5	38.4	3.1	6.6	12.2	13.7	10.9	43	187
T ₁₂ : 50% RDP @ 24 kg ha ⁻¹ + Soil application of 12.5 kg ha ⁻¹ ZnSO ₄ + Nutrient Mobilizer @ 20g kg ⁻¹ seed	5.8	12.0	32.9	39.2	3.1	6.7	13.0	14.0	11.3	44	203
CD (p=0.05)	0.5	1.0	2.7	3.4	0.3	0.9	2.7	3.0	1.4	4	26

treatments (Table 1). At maturity too, T₁₀ produced the tallest plants being significantly superior over that of the other nutrient formulations except T₁₂, T₁₁, T₉, T₇, T₆, T₂ and T₃ which produced statistically similar plants in terms of the plant height. This could be due to synergistic effect of various sources of nutrients known to have beneficial effects in lentil (Singh et al 2017). Ganie et al (2009) in garden pea and Kant et al (2016) in blackgram observed same trend. Singh et al (2013) also reported variations in plant height of lentil crop due to different doses of phosphorus and zinc.

Number of branches: The number of branches increased steadily until maturity, with the growth rate slowing near maturity (Table 1). The highest growth rate occurred between 60 and 90 days. Treatment T₁₀ consistently produced the most branches at all stages. The increased branch number was linked to higher nitrogen uptake during early vegetative stages, supported by phosphorus, which also enhanced root proliferation and the plant's nitrogen-fixing ability. Similar finding was also reported by Kalayu (2019) and Singh et al (2017). Singh et al (2013) also reported that the maximum number of productive branches plant⁻¹ obtained in case of zinc (0.04%) and minimum in control (no application of zinc) in lentil. Thus, zinc and phosphorus both applied at optimum dose increased the number of branches by improving root as well as shoot growth.

Number of compound leaves: Leaf count per plant increased up to the 90 day stage, with the most significant rise between 60 and 90 days, averaging 5.3 leaves per day, compared to 1.12 leaves per day between 30 and 60 days after sowing (Table 1). Treatment T₁₀ consistently produced significantly more leaves than other treatments, except at 60 and 90 days, where it was comparable to T₁₂. Nitrogen, being

a key component of chlorophyll, played a crucial role in leaf development, while optimal phosphorus and zinc uptake enhanced apical branching, further increasing leaf numbers. Kasturikrishna et al (2000) observed that the application of 26.6 kg P₂O₅ ha⁻¹ significantly increased the number of leaves as well as the area of the leaves.

Dry matter accumulation (g plant⁻¹): Dry matter accumulation increased with crop age and the rate of increase between 60 to 90 DAS was the highest at about 0.25 g day⁻¹ (Table 2). The maximum dry matter accumulation at 30, 60 and 90 DAS stages *i.e.* 0.08, 0.7 and 8.2 (g plant⁻¹), respectively, was associated with T₁₀. At 30 DAS and 60 DAS stage, T₁₁ and T₁₂ were statistically on a par with the T₁₀ while at 90 days, T₁₀ and T₁₂ were statistically on a par. Pandey et al (2010) also drew similar conclusion in lentil crop that the plants grown in soil supplied with zinc produced maximum dry matter yield over no zinc application. Similarly, Singh et al (2013) also confirmed that total above ground biomass was influenced by application of zinc. Tagore et al (2013) and Meena et al (2015) came to similar conclusion that the dry matter yield plant⁻¹ increased significantly with inoculation of phosphorus solubilizing microbes

Days taken to flowering: The effect on number of days taken to flowering due to various treatments was non-significant yet the T₁ took the least number of days (73 days) to flowering while T₁₀ took the more number of days (80 days) (Table 2). Days taken to flowering is initiated later when the vegetative growth is lush and more prolonged due to higher uptake of nitrogen. The treatments lacking in nutrients yields flower sooner to mitigate the unfavorable conditions.

Days taken to maturity: Number of days taken to maturity due to different phosphorus and zinc treatments were non-

Table 2. Dry matter accumulation at different stages of crop growth and days taken to flowering and maturity as influenced by phosphorous and zinc treatments

Treatment	Dry matter (g plant ⁻¹)			Number of days taken to	
	30 DAS	60 DAS	90 DAS	Flowering	Maturity
T ₁	0.041	0.34	4.1	73	131
T ₂	0.052	0.51	5.7	76	134
T ₃	0.046	0.47	5.1	75	133
T ₄	0.046	0.46	4.3	75	133
T ₅	0.045	0.34	4.1	74	132
T ₆	0.050	0.51	5.3	75	134
T ₇	0.064	0.53	5.9	76	135
T ₈	0.045	0.43	4.1	75	132
T ₉	0.064	0.54	6.2	77	135
T ₁₀	0.076	0.66	8.2	80	139
T ₁₁	0.068	0.58	7.1	78	136
T ₁₂	0.072	0.62	7.7	78	137
CD (p=0.05)	0.012	0.09	1.0	NS	NS

See Table 1 for details

significant (Table 2). The crop took minimum (131 days) number of days for maturity under T₁ and maximum (138 days) days for maturity under T₁₀. Higher phosphorus application lengthened the period of crop maturity (Rasheed et al 2010).

Grain yield (kg ha⁻¹): Grain yield ha⁻¹ differed significantly due to varying treatments of phosphorus and zinc (Table 3). Treatment T₁₀ produced the maximum grain yield being significantly superior over all the other treatments. Combination of different organic and inorganic and timely availability of the nutrients owing to nutrient solubilizing microbes enhanced the plant growth and significantly increased the grain yield over control (Singh et al 2017). Hussain and Ahmad (2015) reported similar results on effect of phosphorus and zinc on the grain yield.

Straw yield (kg ha⁻¹): Straw yield ha⁻¹ was not influenced significantly due to varying treatments of phosphorus and zinc (Table 3). The highest yield was observed in T₁₀. Phosphorus aids in cell division and help in the development of new tissue and in energy transformation in plants. Enhanced plant growth due to proper availability of nutrients increased the straw yield too. The zinc helped the plant in chlorophyll production and directly contributed in plant growth. Meena et al (2017) observed that the application of phosphorus with zinc resulted in higher grain and straw yield.

Biological yield (kg ha⁻¹): The highest biological yield was obtained from T₁₀ and was statistically superior to all the other treatments (Table 3). Application of phosphorus and zinc to plants increased grain and straw yield and thus, the biological yield. The applied nutrients improved the various parameters of growth and development like plant height, number of

branches plant⁻¹, number of compound leaves plant⁻¹, dry matter accumulation plant⁻¹, the cumulative effect of which ultimately resulted in higher yields of both straw and biological parts. Singh et al (2008) found that the biological yield increased significantly up to 50 kg P₂O₅ ha⁻¹. Different organic and inorganic nutrients might have helped in providing nutrients to the plants and ultimately improving the productivity of lentil (Singh et al 2017).

Grain straw ratio: The variations in grain to straw ratio owing to different treatments was non-significant (Table 3.) The highest ratio was found in treatment T₁₀, T₉ and T₇.

Harvest index: Harvest index varied non-significantly among the different treatment of phosphorus and zinc application (Table 3). The highest harvest index was in T₈ and T₇. Improved crop growth from adequate phosphorus and zinc likely regulated the starch/sucrose ratio in reproductive organs and leaves. Phosphorus enhanced fruiting and facilitated better translocation of essential metabolites to yield-contributing parts, boosting grain yield. Large variations in harvest index are not influenced by any of the given treatments and this might be due to character, highly associated with genetic makeup of the crop (Singh et al 2011). Each increment of phosphorus from (25 to 75 kg ha⁻¹) gave superior HI value of lentil (Fatima et al 2013).

Economic Studies

Gross returns (₹ ha⁻¹): The gross returns was highest in the case of T₁₀ followed by the T₁₂ (Table 3). These returns may be ascribed to the higher yield of the treatments due the balanced application of the nutrients. The higher growth parameters and yield attributes resulted in higher gross returns.

Table 3. Effect of different treatments of phosphorus and zinc on grain, straw, biological yield, grain straw ratio, harvest index, cost of cultivation, net returns and B:C ratio

Treatments	Yield (kg ha ⁻¹)			Grain straw ratio	Harvest index	Net returns (₹ ha ⁻¹)	Cost of cultivation (₹ ha ⁻¹)	B: C ratio
	Grain	Straw	Biological					
T ₁	1318	2591	3909	0.52	0.34	40231	22058	1.82
T ₂	1418	2894	4271	0.49	0.35	43906	23183	1.89
T ₃	1381	2880	4198	0.52	0.33	42005	23308	1.80
T ₄	1363	2731	4179	0.49	0.34	42091	22103	1.90
T ₅	1322	2668	4049	0.49	0.35	40123	22103	1.82
T ₆	1363	2816	4216	0.48	0.33	41791	22148	1.89
T ₇	1522	2890	4298	0.53	0.31	49161	22666	2.17
T ₈	1341	2708	4094	0.49	0.37	40410	22728	1.78
T ₉	1531	2930	4475	0.53	0.33	49293	22711	2.17
T ₁₀	1735	3424	5063	0.53	0.35	58460	23336	2.51
T ₁₁	1544	2980	4502	0.52	0.32	53399	24183	2.21
T ₁₂	1563	3333	4544	0.47	0.33	55101	24246	2.27
CD (p=0.05)	191	NS	383	NS	NS	-	-	-

See Table 1 for details

Net returns (₹ ha⁻¹): The highest net returns was obtained in T₁₀ whereas the minimum net return was in T₁ (Table 3). Yadav et al (2017) observed that the application of phosphorus at 40 kg ha⁻¹ gave significantly higher net returns.

B: C ratio: The highest B:C ratio was obtained in T₁₀ followed by the T₁₂ at 2.27 (Table 3). The minimum was in T₁. This indicates amount of money earned from investment of a unit amount of money. The higher B:C ratio may be ascribed to higher net returns rupee⁻¹ of cost. The nutrients applied caused better output when both phosphorus and zinc were combined along with the solubilizing microbes and led to higher gross and net returns which also led to higher B:C ratio (Singh et al 2019).

CONCLUSION

The application of 50% RDP @24 +12.5 kg ZnSO₄ + Biophos + Biozinc (5 ml kg⁻¹ seed each) proved effective in significantly enhancing the plant height, number of branches plant⁻¹, number of compound leaves plant⁻¹, dry matter accumulation plant⁻¹, number of days taken to flowering and maturity and B: C ratio. The research demonstrates the significant impact of phosphate and zinc solubilizing microbes on growth and yield of lentil. The synergistic interactions between these beneficial microbes and phosphorus and zinc fertilizers not only enhances nutrient availability but also promotes sustainable agricultural practices.

AUTHORS CONTRIBUTION

Monica Yaying: Conceptualization and execution of field experiment and laboratory analysis, data analysis, writing; Anil Shukla: Conceptualization of research work, supervision; Supriya: Preparation of manuscript, editing; Sudarshan S: Data analysis and editing; Shobhana Singh: Editing; Gunashekhar H: Preparation, correction and revision of manuscript; Chandra Bhushan: Correction and revision

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