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Effect of different doses of phosphorus and zinc on lentil (*Lens culinaris* Medik.) with seed inoculation by PSB

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Abstract
A field experiment was conducted during the Rabi season of 2015–16 by KVK, Kushinagar to evaluate the response of lentil cv. PL-8 to phosphorus, zinc and seed inoculation with liquid biofertilizers. Ten treatments were arranged in a randomized block design with three replications. The treatments included an absolute control, the recommended phosphorus dose, zinc sulphate, individual and combined applications of Biophos and Biozinc, and combinations containing reduced phosphorus and zinc doses. Treatment effects were assessed through plant population, plant height, chlorophyll content, nodulation, yield attributes and crop yield. The combined application of 45% recommended phosphorus, 12.0 kg $ZnSO_4$ ha^{-1}, Biophos (PSB)at 5 mL kg^{-1} seed and Biozinc at 5 mL kg^{-1} seed recorded the highest plant height at harvest (25.97 cm), chlorophyll content (3.05 mg g^{-1}), number of nodules (30.62 plant^{-1}), seed yield (2337 kg ha^{-1}), straw yield (4630 kg ha^{-1}) and biological yield (6967 kg ha^{-1}). The recommended phosphorus treatment produced a seed yield of 2219 kg ha^{-1} and a straw yield of 4427 kg ha^{-1}. Based on the reported critical differences, the yields of these two treatments were statistically comparable. Seeds per pod, test weight and harvest index were not significantly affected. The results indicate that the combined treatment produced the numerically highest growth and yield values under the conditions of this single-season experiment.

Keywords: *Lens culinaris*, Biophos (PSB), biozinc, growth attributes, seed yield

Introduction

Pulses are nutrient-dense crops, serving as an excellent source of plant-based protein and micronutrients while being low in fat and high in dietary fibre. Incorporating pulses into a balanced diet actively addresses multiple facets of malnutrition, ranging from undernutrition and micronutrient deficiencies to overweight and obesity. Furthermore, pulses and legumes, in general, play a vital role in maintaining and enhancing soil health. Lentil (*Lens culinaris* L. Medik.), locally known as *masoor*, is one of the most important *Rabi* season grain legumes grown in India. It stands out as a highly nutritious, cool-season, and drought-tolerant crop, containing approximately 24%–26% protein, 1.3% fat, 2.1% minerals, 3.2% fibre, and 57% carbohydrates (Ali *et al*., 2017; Singh *et al*., 2013) [1, 14]. Lentils utilize atmospheric to meet their nitrogen requirements through biological nitrogen fixation (Badarneh and Ghawi, 1994) [3]. This fixation process in legumes is governed by several factors, including specific rhizobial strains as well as the availability of soil nitrogen and phosphorus. Symbiotic nitrogen fixation demands high amounts of P indirectly because the process consumes substantial energy (Schulze *et al*., 2006) [12] and the underlying energy-generating metabolism is strictly dependent on phosphorus availability (Israel, 1987) [6].

Rhizobium and phosphate-solubilizing bacteria (PSB) are well-known to enhance crop productivity by mobilizing soil nitrogen and phosphorus. Among the major plant nutrients, phosphorus is considered one of the primary limiting elements in Indian pulse production. As P is a vital macronutrient required for structural growth and biological development, biofertilizers present a sustainable solution. These products contain carrier-based (solid or liquid) living microorganisms that possess the ability to mobilize chemically unavailable nutrients into plant-absorbable forms through biological processes such as nitrogen fixation, phosphate solubilization, and the excretion of plant growth-promoting substances. In brief, biofertilizers serve as environment-friendly and cost-effective supplements to chemical fertilizers and organic manures, acting as a crucial component of the Integrated Plant Nutrient System (IPNS) to improve soil and crop productivity (Rattan *et al.,* 2015) [11].

Materials and Methods

The experiment was conducted during *Rabi* season of 2015-16. The experiment was laid out on Vertisols with ten treatment combination, replicated three times in randomized block.Test crop of field trial was lentil of variety PL – 8 seed was sowned manually with a spacing of 30 cm x 10 cm row to row and plant to plant. Randomly five plants were selected for measuring height (cm) with the help of meter scale, number of nodules plant^{-1} and mean value was calculated. For counting the number of nodules plant^{-1}. The selected plant sample was uprooted carefully and wash with water for removing the soil mass adhered in roots and counted the pink coloured nodules and mean value was recorded. Number of pods of the five randomly selected plants was counted and their means were computed to express as number of pods plant^{-1}. Number of grains per pod were recorded at harvest by counting the grains of five randomly selected pods from five tagged plants of each plot and average was worked out. One hundred seed were counted from samples of each plot and their weight was recorded as test weight (g). After threshing and winnowing, the clean grains obtained from the produce of individual net plot, were weighed and weight was recorded as grain yield. The grain yield recorded under each plot was converted into kg per hectare (kg ha^{-1}). Straw yield was obtained by subtracting the grain yield (kg ha^{-1}) from biological yield (kg ha^{-1}). Above ground harvestable total biomass produce of each plot tied in bundles was weighed with spring balance after complete sun drying. These results obtained in kg plot^{-1} area were converted in kg ha^{-1} by multiplying factor.

Kushinagar district features a humid subtropical, monsoon-influenced climate. It is characterized by hot, dry summers from April to June (temperatures often exceeding 40°C), heavy monsoon rains from July to September, and cool, dry winters from October to March with temperatures ranging between 10°C and 25°C.

The year is generally divided into three distinct seasons:

- **Summer (April to June):** The hottest months of the year, with daytime temperatures routinely pushing between 35°C and 40°C. Heat waves and dry westerly winds (loo) are common before the monsoon arrives.

- **Monsoon (July to September):** Kushinagar receives the majority of its annual rainfall during this period. The air remains highly humid, and temperatures average around 32°C. Thunderstorms are frequent.

- **Winter (October to March):** Widely considered the most pleasant time of the year and the peak tourism season. Days are cool and sunny (around 25°C), while nights can get quite chilly, occasionally dropping to 10°C or lower.

Results and Discussion

Growth parameters

Application of different treatments of phosphorus, zinc and their liquid bio fertilizer significantly increased the plant height, chlorophyll content, number of nodules per plant, fresh and dry weight of nodules of lentil (table 1 and 2). The application of (50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) attained maximum value of these parameters. This may be attributed primarily to the beneficial effect of fertility on overall physical condition of the soil. The reason for better growth and development in the above treatment might be due to increased availability of zinc and phosphorus to the plant initially through fertilizers, microbial inoculants then through phosphorus, zinc and their liquid bio fertilizer in the cropping season. The increase in growth attributes due to phosphorus helps in early root development and formation of lateral fibrous, healthy roots and root proliferation. P increases the metabolic activities and amount of naturally occurring phytohormones. PSB strains released greater amounts of available Phosphorus and this enable the plant to absorb more Phosphorus resulting in improved growth attributes. Similar results were reported by Kachave *et al.,* (2018) [7]. The better growth in terms of plant height, chlorophyll content, number of nodules plant^{-1}, fresh and dry weight of nodules per plant of lentil, due to application of (50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) as compared to other treatments. The plant height was recorded at 30, 60 DAS, and at harvest. The result revealed that plant height was minimum upto 30 DAS but it was increased during 60 and at harvest due to increase in the age of crop. The plant height value ranges from 18.63cm at 30 DAS, 21.41cm at 60 DAS and 25.97cm at harvest under different treatment. Significantly, maximum plant height value was 21.41cm recorded at 60 DAS and 25.97 at harvest under 50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1} + Biozinc @ 5 ml kg^{-1} and found superior among the treatments. This finding was confirmed by Anant *et al.,* (2021), Kant *et al*., (2016) and Chauhan and Raghav, (2017) [2, 4, 8]. Almost similar trend was also noted with PSB inoculation which might be due to more availability of Phosphorus to plant that may stimulate formation of more nodules. Favourable effect on nodulation appears due to increased Phosphorus supply. The number of nodules decreased at absolute control with advancement of crop age and was significantly affected by different treatments (table 1 and 2). The maximum number of nodules at 45 DAS was recorded *i.e.* 30.62 in treatment T_{10} 50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}, which were superior to rest of the treatments, while minimum number of nodules was recorded in T_1 (Absolute control). Number of nodules at pertinent stage was increased by 68.42 percent in treatment T_{10} 50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1} over absolute control and this result is supported by Kant *et al*., (2016) [8]. Inoculation of T_{10} 50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1} individually increased the number of nodules and fresh and dry weight of root nodules significantly, Results clearly indicates that treatment T_{10} (50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) attained the maximum fresh and dry weight of nodules of 37.04 mg plant^{-1}, 6.61 mg plant^{-1}, were reported by Kumar and Chandra (2008), Navsare *et al.,* (2018) and Kachave *et al.,* (2018) [7, 9, 10].

Yield attributes and yield

Application of different treatments significantly increased the yield attributes such as number of pods plants^{-1}, seeds pod^{-1} and test weight (Table 3). The same trend was also observed in seed, straw and biological yield (Table 3). The application of (50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) attained maximum value of these parameters than rest of the treatments. The result showed that inoculation of phosphate and zinc solubilizing microbes significantly increase the number of pods plant^{-1} in lentil and the result also indicates the positive effect of phosphate and zinc solubilizing microbes on number of pods plant^{-1} ranges from 10 to 200 among different treatment. The result revealed significantly maximum number of pods plant^{-1} 199.11 was recorded under T_{10} 50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}. This finding was confirmed by Anant *et al*., (2021) and Navsare *et al.,* (2018) [2, 10]. The increased seed yield was obtained in organic manure combination with biofertilizers application (*Rhizobium* and PSB) could be attributed to the effect of growth hormones like IAA and cytokinin produced by

Rhizobium which stimulated root morphology. Data pertaining to the efficacy of Phosphorus and inoculation of PSB on straw yield and grain yield of lentil presented in (Table 3). The straw and grain yield of lentil was significantly increased by the application of different levels of Phosphorus alone while the maximum increased in straw and grain yield were reported under the treatment T_{10}-(50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) (2337 and 4630 kg ha^{-1}) followed by T_2- Recommended phosphorus dose (40 kg ha^{-1}) (2219 and 4427 kg ha^{-1}) over absolute control. The increased in straw yield might be due to vigorous start to plant and strength straw yield by Phosphorus application. Similar results were reported by Kachave *et al.,* (2018) [7]. The increase in yield might have resulted from the growth regulating substances produced by biofertilizers besides fixation of additional nitrogen from atmosphere thereby increasing nitrogen availability in the soil throughout the crop growth and this result was reported by Singh and Singh (2017) [13]. The beneficial effect of sulphur and zinc application on yield attributing characteristics have also been recorded by Choudhary *et al.,* (2014) [5] but combination of sulphur and zinc was not found to have significant effect on yield attributes. The maximum increased biological yield was reported under the treatment T_{10}- (50% RD phosphorus + 12.5 kg $ZnSO_4$ + Biophos @ 5 ml kg^{-1}+ Biozinc @ 5 ml kg^{-1}) with value of 6967 kg ha^{-1} compared to other treatments and it was revealed by Kant *et al*., (2016) [8].

Table 1: Effect of phosphorus, zinc and their liquid bio fertilizers on plant stand and plant height

Treatment	Plant population (mrl^{-1})		Plant height $plant^{-1}$ (cm)		
	25 DAS	At harvest	25 DAS	55 DAS	At harvest
T_1- Absolute control	30.13	28.80	11.06	12.71	15.42
T_2- Recommended phosphorus dose (35 kg ha^{-1})	38.95	37.23	17.81	20.47	24.83
T_3- $ZnSO_4$ 20 kg ha^{-1} soil application	35.32	33.76	14.27	16.40	19.90
T_4- Biophos @ 5 ml kg^{-1} Seed	33.88	32.38	13.79	15.85	19.22
T_5- Biozinc @ 5 ml kg^{-1} Seed	35.04	33.49	14.18	16.30	19.77
T_6- Biophos @ 5 ml kg^{-1} Seed + Biozinc @ 5 ml kg^{-1} Seed	34.70	33.16	14.34	16.48	19.99
T_7-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed	36.88	35.25	15.92	18.30	22.19
T_8-12.0 kg $ZnSO_4$ soil application + Biophos @ 5ml kg^{-1} Seed	35.50	33.93	14.38	16.53	20.05
T_9-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed + Biozinc @ 5ml kg^{-1} Seed	37.29	35.64	16.06	18.45	22.39
T_{10}- 45% RD phosphorus soil application + 12.5 kg $ZnSO_4$ soil application + Biophos @ 5 ml kg^{-1} Seed + Biozinc @ 5 ml kg^{-1} Seed	39.32	37.58	18.63	21.41	25.97
S.Em. ±	2.10	1.79	0.71	1.11	0.98
CD at 0.05%	NS	NS	2.10	3.31	2.92

Table 2: Effect of phosphorus, zinc and their liquid bio fertilizers on chlorophyll content (mg g^{-1}), number of nodules per plant, fresh and weight of nodules mg $plant^{-1}$ at 40 DAS

Treatment	Chlorophyll content at 45 DAS mg g^{-1}	Number of nodules $plant^{-1}$ at 45 DAS	Fresh weight nodules (mg $plant^{-1}$)	Dry weight of nodules (mg $plant^{-1}$)
T_1- Absolute control	1.82	18.18	21.99	3.93
T_2- Recommended phosphorus dose (35 kg ha^{-1})	2.90	29.27	35.42	6.32
T_3- $ZnSO_4$ 25 kg ha^{-1} soil application	2.33	23.46	28.38	5.07
T_4- Biophos @ 5 ml kg^{-1} Seed	2.26	22.66	27.42	4.90
T_5- Biozinc @ 5 ml kg^{-1} Seed	2.33	23.31	28.20	5.04
T_6- Biophos @ 5 ml kg^{-1} Seed + Biozinc @ 5 ml kg^{-1} Seed	2.34	23.57	28.51	5.09
T_7-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed	2.60	26.17	31.65	5.65
T_8-12.50 kg $ZnSO_4$ soil application + Biophos @ 5ml kg^{-1} Seed	2.37	23.64	28.60	5.11
T_9-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed + Biozinc @ 5ml kg^{-1} Seed	2.63	26.39	31.93	5.70
T_{10}- 45% RD phosphorus soil application + 12.5 kg $ZnSO_4$ soil application + Biophos @ 5 ml kg^{-1} Seed + Biozinc @ 5 ml kg^{-1} Seed	3.05	30.62	37.04	6.61
S.Em. ±	0.07	1.25	2.01	0.30
CD at 0.05%	0.22	3.70	5.97	0.88

Table 3: Effect of phosphorus, zinc and their liquid bio fertilizers on pods per plant, seed per pod and test weight, seed yield, haulm yield, biological yield and harvest index at harvest

Treatment	Pods $plant^{-1}$	Seeds pod^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest Index (%)
T_1- Absolute control	118.22	1.29	1.99	1384	2750	4134	33.73
T_2- Recommended phosphorus dose (35 kg ha^{-1})	190.39	1.69	2.21	2219	4427	6645	33.59
T_3- $ZnSO_4$ 20 kg ha^{-1} soil application	152.54	1.52	2.16	1776	3549	5326	33.54
T_4- Biophos @ 5 ml kg^{-1} Seed	147.38	1.50	2.15	1716	3424	5140	33.43
T_5- Biozinc @ 5 ml kg^{-1} Seed	151.60	1.53	2.17	1766	3528	5294	33.31
T_6- Biophos @ 5 ml kg^{-1} Seed +	153.27	1.54	2.17	1770	3529	5299	33.37

Biozinc @ 5 ml kg^{-1} Seed							
T_7-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed	170.17	1.62	2.20	1994	3949	5943	33.62
T_8-12.50 kg $ZnSO_4$ soil application + Biophos @ 5ml kg^{-1} Seed	153.76	1.53	2.16	1795	3577	5371	33.47
T_9-45% RD phosphorus soil application + Biophos @ 5ml kg^{-1} Seed + Biozinc @ 5ml kg^{-1} Seed	171.63	1.60	2.16	2001	3989	5989	33.39
T_{10}- 45% RD phosphorus soil application + 12.5 kg $ZnSO_4$ soil application + Biophos @ 5 ml kg^{-1} Seed + Biozinc @ 5 ml kg^{-1} Seed	199.11	1.71	2.21	2337	4630	6967	33.61
S.Em. ±	7.96	0.08	0.07	76	206	217	1.69
CD at 0.05%	23.64	NS	NS	226	612	643	NS

Lentil demonstration at farmers fields

Conclusion

The application of phosphorus, zinc and liquid microbial inoculants influenced lentil growth, nodulation and yield. The combination of 45% recommended phosphorus, 12.5 kg $ZnSO_4$ ha^{-1}, Biophos and Biozinc recorded the highest numerical values for plant height, chlorophyll content, nodulation, seed yield, straw yield and biological yield. However, its seed and straw yields were statistically comparable with those obtained using the full recommended phosphorus dose. Seeds per pod, test weight and harvest index were not significantly affected by the treatments. The combined treatment may therefore provide an alternative nutrient-management option under the tested conditions, but its fertilizer-saving potential, economic advantage and consistency require confirmation through additional seasons and locations.

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