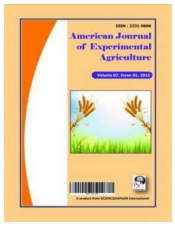

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Productivity of Lentil (*Lens culinaris* L.*)* as Influenced by Organic and Inorganic Fertilizers

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Authors' contributions

This work was carried out in collaboration between all authors. Author SR designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SH reviewed the experimental design and all drafts of the manuscript. Authors SH and MHK managed the analyses of the study. Authors SR and MHK performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the growth and yield of lentil as influenced by organic (*Rhizobium* and phosphate solubilizing bacteria) and inorganic fertilizers (four levels of phosphorus viz., 0, 20, 40 & 60 kg P_20_5/ha and recommended dose of nitrogen and potassium)
Study Design: Randomized block design (RBD) with three replications
Place and Duration of Study: A field experiment was conducted during winter season of 2012-2013 at Agronomy Research Farm, CSKHPKV, Palampur, HP, India.
Methodology: The experiment consisted of 16 treatments comprising of four levels each of biofertilizer (UI= uninoculated, In_{Rh}= inoculation with *Rhizobium*, In_{PSB}= inoculation with phosphate solubilizing bacteria & $In_{Rh\ +PSB}$= inoculation with both *Rhizobium* and phosphate solubilizing bacteria) and phosphorus (0, 20, 40 & 60 kg P_20_5/ha).
Results: Seed and straw yield of lentil was significantly influenced by the different treatments. Significantly higher yield of lentil was obtained in the plots sown with inoculated seed over

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uninoculated seed (UI). Higher seed as well as straw yield was recorded in the plots treated with phosphorus application over control (Po). Combined inoculation with *Rhizobium* and phosphate solubilizing bacteria produced the highest seed and straw yield. The highest yield was recorded in the plots received phosphorus 60 kg P_20_5 per hectare but the maximum response (kg seed/ kg P_20_5) was at P_{40}. Interaction between biofertilizers and phosphorus levels was also significant in respect of seed as will as straw yield. The maximum yield was recorded in the plots sown with inoculated seed with both biofertilizers and applied 60 kg P_20_5 per ha ($In_{Rh+PSB} + P_{60}$).

Conclusion: The study concluded that lentil responded better to phosphorus application upto 60 kg P_20_5/ha in combination with seed inoculation with *Rhizobium* and phosphate solubilizing bacteria.

Keywords: Lentil; seed and straw yield; phosphorus; Rhizobium; phosphate solubilizing bacteria.

1. INTRODUCTION

Lentil (*Lens culinaris* L.) is an important winter pulse crop grown in Indian sub-continent. In Himachal Pradesh, lentil is the second important rabi pulse crop after chickpea. The area under lentil in H.P. is 600 ha and its productivity is about 667 kg/ha which is low as compared to the national average [1]. Lentil like other pulse crops has been given the secondary importance and is grown on marginal lands with low fertility and receives sub-optimal fertilizer application. It has shown good response to the application of phosphorus as reported by [2,3]. *Rhizobium* and phosphate solubilizing bacteria are known to benefit the crop by increasing the availability of soil nitrogen and phosphorus [4]. The present investigation was carried out to evaluate the effect of biofertilizers and phosphorus levels on lentil production.

2. MATERIALS AND METHODS

A field experiment was conducted during winter season of 2012-13 at Agronomy Research Farm, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, situated in mid-hill sub-humid conditions of Himachal Pradesh, India. The soil of experimental field was silty clay loam in texture, acidic in reaction (pH 6.5) and medium in available nitrogen, phosphorus and potassium. The experiment comprised of 16 treatments of four levels each of biofertilizer (UI= uninoculated, In_{Rh}= inoculation with *Rhizobium*, In_{PSB}= inoculation with phosphate solubilizing bacteria & $In_{Rh\ +PSB}$= inoculation with both *Rhizobium* and phosphate solubilizing bacteria) and phosphorus (0, 20, 40 & 60 kg P_20_5/ha) was laid in randomized block design (RBD) with three replications having plot size of 3.1 x 3.3 m. Lentil variety HPL-5 was used as an experimental material. Row to row spacing was kept 30 cm. The chemical fertilizers Urea, single super phosphate and muriate of potash were used as source of nitrogen, phosphorus and potassium, respectively. Full dose of phosphorus and potassium and basal dose of nitrogen (10 kg/ha) were applied. The healthy seeds of lentil were inoculated with *Rhizobium* and phosphate solubilizing bacteria cultures (50 g kg^{-1} seed) before sowing and were applied to the respective plots as per the layout plan.

The data obtained in respect of various observations were statistically analyzed by the method described by [5]. The significance of "F" and "t" was tested at 5 per cent level of significance.

3. RESULTS AND DISCUSSION

3.1 Effect of *Rhizobium*

Perusal of the data presented in Table 1 revealed that number of plants/m^2, plant height, dry matter accumulation and number of nodules/plant were significantly highest in combined treatment of seed inoculation with *Rhizobium* and phosphate solubilizing bacteria but remained at par with inoculation with phosphate solubilizing bacteria as compared to uninoculated and seed treated with *Rhizobium* treatments. Seed inoculation with *Rhizobium* (In_{Rh}) significantly increased (11%) the seed yield over the uninoculated seed treatment (Table 2). It may be due to increase in the availability of soil nitrogen to the plants for increased growth and development as *Rhizobium* present in root nodules of lentil fix atmospheric nitrogen. [6-9] also reported the similar findings.

3.2 Effect of Phosphate Solubilizing Bacteria

The mean values of the growth parameters viz., no. of plants/m^2, plant height, dry matter

accumulation and no. of nodules/plant and yield attributes viz., no. of plants/m^2 (at harvest), no. of primary branches/plant, no. of pods/plant, no. of seeds/pod, test weight, biological yield and harvest index were higher as compared to the control treatment, however, they were significantly similar with control and other treatments of phosphate solubilizing bacteria (Tables 1 and 2). Seed inoculated with phosphate solubilizing bacteria produced significantly higher seed as well as straw yield. Seed yield recorded in the plots sown with seed inoculated with PSB was 7% and 9% higher as compared to seed inoculated with *Rhizobium* and uninoculated seed, respectively (Table 2). The phosphate solubilizing bacteria help to release unavailable soil phosphorus and may increase the efficiency of applied phosphatic fertilizers. Similar results were also reported by [10,11]. Singh and Prasad [12] reported that reported that plant growth promoting rhizobacteria provided significant influence on plant growth, nodulation, yield and attribution of traits in lentil. Plant growth promoting microbes are important contributor to biofertilization of agricultural crops. Ponmurugan and Gopi [13] studied the production of growth regulators by phosphate solubilizing bacteria, while, [14] reported that treatment with phosphate solubilizing bacteria resulted in increased yield of pea and barley. These results were close agreement with [7] and [6] for plant growth promotion, nodulation and seed yield in urdbean with *Rhizobium* and soybean with PSB, respectively. Therefore, the study suggested that phosphate solubilizing bacterial isolates are capable of enhancing the plant height, nodulation, seed yield and its contributing traits by secreting plant growth promoting substances. That is why the evaluated P solubilizing bacterial isolates were important contributor to improve plant growth and seed yield in lentil. The use of PGPR as inoculants biofertilizers is an efficient approach to replace chemical fertilizers and pesticides for sustainable lentil cultivation.

3.3 Combined Effect of *Rhizobium* and Phosphate Solubilizing Bacteria

Combined inoculation with *Rhizobium* and phosphate solubilizing bacteria produced significantly higher growth and yield attributes as well as seed and straw yield (Tables 1 and 2). Increase of 29% in seed yield and 17% in straw yield was recorded in the plots treated with both *Rhizobium* and phosphate solubilizing bacteria. These results may be due to the increased availability of nitrogen and phosphorus to the plants which in turn results into enhanced absorption of nutrients. El Sayed [4] also observed the same effect. Jilani et al. [15] reported that the PSB and plant growth promoting rhizobacteria (PGPR) together could reduce P fertilizer application by 50% without any significant reduction in crop yield. Therefore, it can be speculated that PSB inoculants / biofertilizers hold great prospects for sustaining crop production with optimized P fertilization. Kumar and Chandra [16] also observed that inoculation of lentil seeds by PSB increased significantly grain (23.5%) and straw yield (14.0%) of lentil. The present study is well accordance with those earlier findings. The results of [17] are in close agreement with the present findings who found significant differences in grain and straw yields due to microbial inoculation. The grain and straw yields increased due to microbial inoculation, and the highest seed and straw yields were obtained in inoculation of *Rhizobium* + PSB and the lowest in the case of control. The increase in grain and straw yield might be attributed to the increased availability of N and P in soil which resulted in higher growth and development and finally yields [18].

3.4 Effect of Phosphorus

Phosphorus application significantly increased growth as well as seed and straw yield of lentil (Tables 1 and 2). A perusal of data revealed that 60 kg P_20_5/ha and 40 kg P_20_5/ha at par with one another significantly increased no. of plants/m^2, plant height, dry matter accumulation and no. of nodules/plant over control (0 kg P_20_5/ha). The highest seed yield was produced with 60 kg P_20_5/ha but the maximum response (kg seed/ kg P_20_5) was with 40 kg P_20_5/ha. Phosphorus 60 kg P_20_5/ha gave 61%, 57% and 11% higher seed yield over P_o (control), P_{20} and P_{40}, respectively. It may be due to the favourable effect of phosphorus on root and root nodulation development at initial stages and on yield components at later stages. The present results corroborate to the findings of [19]. The findings of [20] are very similar to current findings who reported that application of phosphorous up to 60 kg ha^{-1} increased growth, nodulation, yield attributes, yield and nutrient uptake and was found at par with 45 kg ha^{-1} .The seed yield obtained with 60 kg P_2O_5 ha was 42.5, 22.59 and 1.93% higher over 0, 30 and 45 kg P_2O_5 ha^{-1}, respectively, obviously due to improvement in nodulation, crop growth and yield attributes. Kumari et al. [10,21] reported that these results

Table 1. Effect of biofertilizers and phosphorus levels on the growth of lentil

Treatment	No. of plants/m^2		Plant height (cm)			Dry matter accumulation			No. of nodules/plant	
	90 DAS	120 DAS	90 DAS	120 DAS	At Harvest	90 DAS	120 DAS	At Harvest	90 DAS	120 DAS
P_0	58	50	11.75	21.83	24.83	24.33	52.88	130.18	4.00	6.16
P_{20}	75	71	12.41	23.41	27.00	28.53	62.36	146.19	4.25	6.83
P_{40}	87	83	14.08	26.66	29.41	33.00	70.04	185.97	4.75	8.00
P_{60}	96	93	15 .08	27.41	29.91	36.29	78.73	201.70	6.00	8.75
C.D. at 5%	11.98	9.37	1.16	2.28	2.10	1.87	7.76	20.47	0.73	1.14
UI	73	70	12.66	23.25	26.16	29.69	60.30	154.94	4.08	6.74
In_{Rh}	76	74	13.16	24.58	27.66	29.61	64.62	159.63	4.91	7.41
In_{PSB}	79	75	13.16	25.41	27.91	29.69	63.85	163.92	4.66	7.24
In_{Rh+PSB}	88	84	14.33	26.08	29.41	33.16	75.24	185.54	5.33	8.33
C.D at 5%	NS	9.37	1 .16	NS	2.10	1.87	7.76	20.47	0.73	NS

Where C.D: Critical difference
NS; Non-significant

Table 2. Effect of biofertilizers and phosphorus levels on yield attributes and yield of lentil

Treatment	No. of plants/m^2 (at harvest)	No. of primary branches/plant	No. of pods/plant	No. of seeds/pod	Test weight (g)	Biological yield kg/ha	Seed yield kg/ha	Straw yiel kg/ha	Harvest index (%)
P_0	57	3.83	49.91	1.68	2.40	139 4	492	902	35
P_{20}	68	4.33	54.91	1.71	2.41	1480	506	974	34
P_{40}	82	5.08	70.33	1.79	2.57	2012	713	1299	35
P_{60}	88	5.33	78.41	1.80	2.561	2192	794	1377	36
C.D at 5%	5.78	0.61	4.61	0.02	0.14	83.49	26.68	75.01	NS
UI	64	4.25	54.16	1.72	2.48	1612	544.80	1067	34
In_{Rh}	74	4.67	62.41	1.75	2.50	1737	605.15	1132	35
In_{PSB}	74	4.58	66.16	1. 74	2.45	1770	649.00	1121	36
In_{Rh+PSB}	79	5.08	70.83	1.77	2.57	1959	706.48	1253	35
C.D at 5%	5.78	0.61	4.61	0.02	NS	83.49	26.68	75.01	1.6

Where C.D: Critical difference
NS; Non-significant

might be due to the fact that application of phosphorous improved the nutrient availability, resulting into greater uptake which might have increased the photosynthesis and translocation of assimilates to different parts for enhanced growth and yield of the crop. In later stage, more assimilates were produced than used in growth and development and the excess assimilates were diverted to storage compounds resulting into increased seed yield.

3.5 Interaction Effect of Biofertilizers and Phosphorus Levels

Seed inoculation with both *Rhizobium* and phosphate solubilizing bacteria in combination with phosphorus 60 kg P_2O_5/ha significantly increased the seed and straw yield of lentil (Table 2). The higher seed and straw yield was recorded in the plots treated with both *Rhizobium* and phosphate solubilizing bacteria combined with application of phosphorus 60 kg P_20_5/ha. These results are in conformity with those of [22]. Haque and Khan [23] reported that phosphatic biofertilizer with inorganic or organic sources of P influenced the growth and yield attributes and yields of lentil. The results of [20] matches with the present findings that maximum seed yield was recorded in the seed inoculation conjointly with *Rhizobium* + PSB along with application of 60 kg P_2O_5/ha and it was statistically at par with the seed inoculation conjointly with *Rhizobium* + PSB plus application of 45 kg P_2O_5/ha. Therefore, seed inoculation with *Rhizobium* + PSB along with 45 kg P_2O_5/ha may be effectively recommended for improving crop growth, microbial population in respect of soil health, nodulation and seed yield of lentil.

4. CONCLUSIONS

It can be concluded that lentil responded to phosphorus application upto 60 kg P_20_5/ha but the maximum response, kg seed per kg P_20_5 was with 40 kg P_20_5 /ha. Seed inoculated with *Rhizobium* and phosphate solubilizing bacteria in combination was proved to be superior over inoculation with either of biofertilizers. Interaction among *Rhizobium*, phosphate solubilizing bacteria and phosphorus application was significant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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