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Research Paper

Effect of integrated use of rock phosphate, molybdenum and phosphate solubilizing bacteria on lentil (*Lens culinaris*) in an alluvial soil

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ABSTRACT

A field experiment was conducted at Gamari, Agra, Uttar Pradesh during the winter (*rabi*) season of 2009–10 and 2010–11 on phosphate-deficient soil, to study the combined effect of rockphosphate (RP) with molybdenum and phosphate-solubilizing bacteria (PSB) on yield and quality of lentil (*Lens culinaris* Medik.) and soil fertility. Application of 60 kg P_2O_5 + 2 kg Mo/ha + *Pseudomonas striata* recorded significantly taller plants (49 cm), highest branches/plant (10.4), pods/plant (103.5) and test weight (28.5 g). The lentil crop responded significantly up to 60 kg P_2O_5/ha as rockphosphate and increased the grain and straw yields by 17.2 and 19.8% respectively. Application of 2 kg Mo/ha proved superior to the control with respect to grain and straw yields. *Pseudomonas striata* inoculation along with 2 kg Mo/ha or 60 kg P_2O_5/ha as rockphosphate improved the yield of lentil significantly over the control. The maximum grain (1.75 t/ha) and straw (3.9 t/ha) yields, and protein content were recorded with conjunctive use of 60 kg P_2O_5/ha as rockphosphate + 2 kg Mo/ha + *Pseudomonas striata* inoculation. The utilization of nutrients by lentil and status of available N (166 kg/ha), P (13 kg/ha) and Mo (0.074 mg/kg) improved significantly owing to P source + Mo + inoculation with *Pseudomonas striata* over the control. Maximum net returns (₹63,150/ha) and benefit: cost ratio (4.30) were obtained with 60 kg P_2O_5 + 2 kg Mo/ha + *P. striata* and 30 kg P_2O_5 + 2 kg Mo + *P. striata* inoculation respectively. The P-use efficiency decreased and apparent P recovery increased with increasing dose of phosphorus.

Key words : Lentil, Nutrient management, Nutrient uptake, Pulse production, Yield

Phosphorus is the second most limiting nutrient after nitrogen in majority of the soils for crop production. The requirement for P which is essential for root growth and nodulation has to be fulfilled largely through inorganic fertilizers. The cost of applying conventional water-soluble P fertilizer is high because of high manufacturing cost involved in importing high-grade rockphosphate (RP) and sulphur. Finely-ground (100 mesh) low-grade Udaipur rockphosphate was procured from Rajasthan State Mines and Minerals Ltd, Udaipur, Rajasthan. It was alkaline (pH 7.5) with electrical conductivity of 0.80 dS/m, total P_2O_5 17.5%, citrate soluble P_2O_5 0.12% (0.68% of total P_2O_5) and water-soluble P_2O_5 in traces. This urgently calls for an improvement in the effectiveness of rockphosphate and efficient utilization of P by the crops in neutral and alkaline soils. So, the vast potential of this native rock phosphate can be exploited in order to reduce the dependence of farmers entirely on water-soluble P fertilizer. Molybdenum is an essential component of the enzyme nitrate reductase, which catalyzes the conversion of NO_3 to NO_2. It is also a structural component of enzyme nitrogenase, which is actively involved in atmospheric N_2 fixation by root-nodule bacteria of leguminous crops. Molybdenum acts in enzyme system which brings about oxidation-reduction reactions, especially the reduction of nitrate to ammonia prior to amino acids and protein synthesis in the cells of plant besides activator of dehydrogeneses and co-factor in the synthesis of ascorbic acid. Molybdenum is considered as one of the constraints in the optimum nodulation of leguminous crops. Introduction of P-solubilizing microorganisms in the rhizosphere of crop and soil increases the availability of P from insoluble sources of phosphates, desorption of fixed phosphates and also increases the efficiency of phosphatic fertilizer (Gaur, 1990).

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The present study was undertaken to study the effect of rockphosphate along with molybdenum and P-solubilizers on lentil crop in an alluvial soil.

MATERIALS AND METHODS

A field experiment was conducted at farmers field during the winter (*rabi*) season of 2009–10 and 2010–11 at Gamari village, Agra, Uttar Pradesh. The soil was sandy loam with alkaline reaction (pH 8.0 and 8.1), organic carbon (2.9 and 3.1 g/kg), available N (146 and 150 kg/ha), P (8.5 and 8.6 kg/ha) and K (100 and 105 kg/ha), respectively, in 2009–10 and 2010-11. The soil contained 0.040 mg/kg available Mo. The experiment was conducted in a randomized block design replicated thrice. The treatments were: T_1, control; T_2, 2 kg Mo/ha; T_3, 2 kg Mo/ha + inoculation of *P. striata;* T_4, 30 kg P_2O_5/ha as RP; T_5, 30 kg P_2O_5/ha as rockphosphate + 2 kg Mo/ha; T_6, 30 kg P_2O_5/ha as RP + inoculation of *P. striata* + 2 kg Mo/ha; T_7, 60 kg P_2O_5/ha as RP; T_8, 60 kg P_2O_5/ha as RP+ 2 kg Mo/ha; T_9, 60 kg P_2O_5/ha as RP+ inoculation of *P. striata* + 2 kg Mo/ha. A basal dose of 20 kg N through urea and 60 kg K_2O/ha through muriate of potash was applied uniformly in all the plots. Rockphosphate was applied 15 days before sowing of the crop, whereas molybdenum as sodium molybdate was applied at the time of sowing. Seeds of lentil were treated with *Pseudomonas striata* strain as per treatment before sowing. Lentil var. 'T 36' was sown during the last week of November in both the years. Rest of the management practices were in accordance with the recommended package of practices for the crop. Grain and straw yields were recorded at harvesting. Plant samples (grain + straw) were dried at 50°C, ground and digested in diacid mixture (HNO_3 : $HClO_4$, 10 : 4 by volume) and the extract was analysed for P by vanadomolybdate yellow colour method, K by flame photometer and Mo by thiocyanate method. Nitrogen content in grain and straw was determined by modified Kjeldahl method (Jackson, 1973). The soil samples collected after harvesting were analyzed for available N, P, and Mo as per procedures suggested by Jackson (1973). Agronomic efficiency was computed with the formula given below:

$$\text{Agronomic efficiency (kg grain/ kg P applied} = (Y_t - Y_0)\ Pa$$

where Y_t = grain yield (kg/ha) in test treatment; Y_0 = grain yield (kg/ha) in the control plot; Pa = Phosphorus applied in test treatment (kg/ha).

The apparent P recovery was worked out as follows:

$$\text{Apparent P recovery (\%)} = \frac{\text{Uptake in treated plot} - \text{Uptake in control plot}}{\text{Fertilizer dose}} \times 100$$

Economics of different treatments was worked out on the basis of input and output on the prevailing market prices.

RESULTS AND DISCUSSION

Growth and yield attributes

Most of the treatments either alone or in combination significantly improved the plant height, branches/plant and pods/plants over the control (Table 1). Application of 60 kg P_2O_5 as RP + 2 kg Mo/ha and *P. striata* inoculation produced significantly taller plants than other treatments. Branches/plant and pods/plant were maximum with 60 kg P_2O_5 + 2 kg Mo/ha + P. striata inoculation and were significantly more than the control. This behaviour of treatments may be attributed to differential availability of phosphorus under different treatments. This might be the result of improved supply of phosphorus by *P.striata* at the later stages of crop growth. Khan *et al.* (2007) reported significant increase in number if pods/plants with biofertilizers. Application of rockphosphate (30 or 60 kg P_2O_5/ha) + *P. striata* inoculation enhanced these attributes significantly over the control. Different treatments alone or in combination had no significant influence on test weight (1,000-grain weight) in lentil compared to the control.

Crop yield

Pooled data showed 7.9 and 8.2% increase in grain and straw yield of lentil (table 2) with the application of 2 kg Mo/ha over the control which might be owing to better nutritional environment in term of increased nitrogen fixation and increased plant growth. Molybdenum is known to be essential for N_2-fixation by rhizobia in legumes, being a component of nitrate-reductase enzyme which controls the reduction of inorganic NO_3 and helps in fixing nitrogen as NH_3 as a result occurs increased nodulation, growth, grain and straw yield. These results confirm the findings of Kumawat *et al.* (2009). Significant increase in grain and straw yield was recorded with 2 kg Mo/ha + *Pseudomonas striata* inoculation treatment over the control. The increase in yield with inoculation of P-solubilizing microorganisms may be due to increase in P availability through solubilization of insoluble inorganic phosphate, decomposition of phosphate rich organic compounds and production of plant-growth promoting substances (Gaur and Sunita, 1999). Application of rockphosphate had also significantly influenced the grain and straw yields of lentil. The increase in grain and straw yield with 60 kg P_2O_5/ha (RP) alone over the control was recorded to the tune of 2.15 and 4.64 q/ha respectively. Grain and straw yield of lentil was also significantly influenced with combined application of rockphosphate @ 30 and 60 kg P_2O_5 along with 2 kg Mo/ha. Improved environment in rhizosphere coupled with more balanced nutri-

tional environment inside the plant owing to P and Mo application increased the plant growth resulting in higher grain and straw yields. These results are in agreement with the findings of Chaudhary and Das (1996). Conjoint use of 60 kg P_2O_5/ha as RP + 2 kg Mo/ha + *P. striata* inoculation was found to be significantly superior than rest of the treatments in terms of grain and strow yield (Aziz Qureshi *et al.,* 2005).

Grain quality

Different treatments significantly increased the protein content in lentil crop over the control (Table 2). Application of 2 kg Mo/ha improved the content of protein from 21.2 to 21.65%. Application of rockphosphate (30 or 60 kg P_2O_5/ha in the presence of Mo significantly improved the protein percentage. This increase in protein content with P application might be due to higher N absorption as a result of increased N fixation by nodules (Majumdar *et al.,* 2007). The maximum protein content in grain (22.1%) and straw (4.6%) was recorded with combined use of 2 kg Mo + 60 kg P_2O_5/ha as RP and *P. striata* inoculation. The protein yield ranged from 263.9 kg/ha at control to 380.2 kg/ ha at 60 kg P_2O_5 + 2 kg Mo/ha + *P. striata* inoculation.

Nutrient uptake

The mean uptake of nitrogen by lentil improved markedly with all the treatments over the control. The nitrogen uptake increased by 4.4 kg/ha by grain and 3 kg/ha by straw with 2 kg Mo/ha over the control. Higher values of N uptake with Mo application are apparently the result of favourable effect of Mo on the nitrogen content coupled with higher grain and straw yield. Kumawat *et al.* (2009) also reported a beneficial effect of Mo on the nitrogen uptake by legumes. Inoculation with *P. striata* amended with molybdenum enhanced the uptake of nitrogen by lentil grain and straw over the control. Rockphosphate levels also improved the utilization of nitrogen by lentil crop significantly over the control. But the differences between

Table 1. Effect of rockphosphate, molybdenum and phosphate-solubilizing bacteria on growth and yield attributes of lentil (mean data of 2 years)

Treatment	Plant height (cm)	Branches/plant	Pods/plant	Test weight (g)
Control	38.0	5.1	74.0	28.0
2 kg Mo/ha	39.2	5.6	82.2	28.0
2 kg Mo/ha + *P. striata*	40.8	6.2	90.5	28.1
30 kg P_2O_5/ha as RP	42.0	7.0	96.7	28.2
30 kg P_2O_5/ha as RP + 2 kg Mo/ha	43.8	7.8	98.0	28.3
30 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	45.0	8.4	99.4	28.3
60 kg P_2O_5/ha as RP	46.2	9.0	100.0	28.2
60 kg P_2O_5/ha as RP + 2 kg Mo/ha	47.4	9.6	101.0	28.4
60 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	49.0	10.4	103.5	28.5
SEm±	0.88	0.18	4.59	0.17
CD (P=0.05)	2.60	0.53	13.71	NS

P. Striata, Pseudomonas striata; RP, rockphosphate

Table 2. Effect of rockphosphate, molybdenum and phosphate-solubilizing bacteria on yield and protein content of lentil (mean data of 2 years)

Treatment	Yield (t/ha)		Protein content (%)		Protein yield grain (kg/ha)
	Grain	Straw	Grain	Straw	
Control	1.25	2.34	21.18	3.59	263.9
2 kg Mo/ha	1.35	2.53	21.65	3.68	291.2
2 kg Mo/ha + *P. striata*	1.41	2.77	21.68	4.06	305.2
30 kg P_2O_5/ha as RP	1.35	2.55	21.37	4.00	289.3
30 kg P_2O_5/ha as RP + 2 kg Mo/ha	1.46	2.75	21.81	4.18	317.8
30 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	1.65	3.09	21.12	4.05	348.0
60 kg P_2O_5/ha as RP	1.46	2.81	21.52	4.11	314.4
60 kg P_2O_5/ha as RP + 2 kg Mo/ha	1.67	3.13	21.93	4.31	366.6
60 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	1.75	3.29	22.06	4.56	380.2
SEm±	0.05	0.08	0.26	0.01	1.2
CD (P=0.05)	0.14	0.25	0.55	0.15	20.0

P. Striata, Pseudomonas striata; RP, rockphosphate

rockphosphate levels were non-significant. The uptake of nitrogen was further improved when rockphosphate-treated soil was inoculated with *P. striata*. The maximum nitrogen uptake was recorded with 60 kg P_2O_5/ha as rockphosphate + 2 kg Mo/ha + *P. striata* inoculation, which were significantly superior to most of the treatments. Molybdenum application augmented the amount of phosphorus assimilated by grain and straw which may be due to both the higher content of phosphorus and the grain and straw production. The beneficial effect of Mo application on P uptake was also reported by Kumawat *et al.* (2009) in green gram. The combined application of 2 kg Mo/ha and *P. striata* inoculation enhanced the effectiveness of *P. striata* in increasing the utilization of phosphorus by crop. The high level of rockphosphate could probably maintain the available P status in soil to facilitate its uptake at an optimum level. The P uptake with *P. striata* was comparable with higher level of rockphosphate but significantly superior to low level of rockphosphate alone. This might be owing to increased P availability and grain and straw yield. The highest P uptake was recorded with 60 kg P_2O_5/ha as RP + 2 kg Mo/ha + *P. striata* treatment which differed significantly from most of the treatments. The higher P utilization by lentil crop could be attained because of increased microbial activity in improving the availability of soil nutrients for their absorption.

The straw portion of the crop utilized higher amount of potassium than grain in all the treatments which may be attributed to greater concentration of K in straw. The K uptake was not affected with Mo application; however, a slight increase was noticed with applied Mo. The combined treatment of molybdenum and *Psudomonas striata* inoculation removed greater amount of potassium from the soil through grain and straw of the crop. Application of rockphosphate also improved the utilization of potassium and the best results were obtained with the addition of 60 kg P_2O_5/ha as rockphosphate. Application of rockphosphate along with *Pseudomonas striata* and Mo resulted in significant increase in the utilization of potassium by grain and straw. The increase in K uptake under this treatment might be the outcome of increased content of K in grain and straw coupled with increased grain and straw production. It is further apparent from the data (Table 3) that most of the treatments significantly improved the utilization of Mo by grain and straw over the control and maximum uptake (9.5 and 12.1 g/ha) was recorded with 61 kg P_2O_5 + 2 Kg Mo/ha + *P. striata* inoculation. Kumawat *et al.* (2009) also reported increased Mo concentration and consequently its uptake. Application of molybdenum along with *Pseudomonas striata* inoculation proved beneficial, as they enhanced Mo uptake significantly. However, the increase in molybdenum uptake due to this treatment was statistically non-significant over 2 kg Mo/ha alone. The uptake of Mo by lentil grain and straw also increased slightly with rockphosphate levels. All the treatments where molybdenum was applied gave good results than no-Mo treatments. The maximum molybdenum uptake in grain and straw was recorded by integrated use of 60 kg P_2O_5 + 2 kg Mo/ha + *P. striata* and minimum in control.

Available nutrients in soil

The minimum value of available nitrogen content in soil was recorded in the control (Table 4), which may be ascribed to greater utilization of nitrogen by lentil crop. The status of available nitrogen in soil was not affected significantly with *P. striata* inoculation. Molybdenum application improved the status of available N in soil as com-

Table 3. Effect of rockphosphate, molybdenum and phosphate-solubilizing bacteria on N, P, K (kg/ha) and Mo (g/ha) uptake in lentil (mean data of 2 years)

Treatment	N		P		K		Mo	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	42.2	13.4	2.4	2.0	9.8	41.4	3.5	4.1
T_2	46.6	16.4	2.8	2.2	10.7	45.2	5.5	6.8
T_3	51.3	18.0	3.4	2.9	11.9	50.2	6.6	8.2
T_4	50.5	17.5	3.3	2.4	11.9	49.6	4.5	5.3
T_5	54.9	19.7	3.8	4.2	12.9	53.4	7.1	9.2
T_6	58.0	20.9	4.2	4.9	13.6	57.1	8.2	10.2
T_7	55.3	20.1	3.9	4.2	13.0	53.7	5.4	8.5
T_8	60.0	23.0	4.6	4.9	14.2	58.2	8.7	11.1
T_9	63.4	24.8	5.2	5.4	15.2	62.0	9.5	12.1
SEm±	2.53	1.66	0.26	0.29	0.84	2.72	0.53	0.68
CD (P=0.05)	7.60	4.98	0.77	0.84	2.53	8.17	1.59	2.03

P. Striata, Pseudomonas striata; RP, rockphosphate

pared to the control. Rockphosphate levels also improved the status of N in soil after the harvesting of crop, indicating its substantial build up owing to increased biological N fixation (Majumdar *et al.,* 2007). Treatment 60 kg P_2O_5 + 2 kg Mo/ha + *P. striata* was the best in enhancing the status of available nitrogen (166 kg/ha). The amount of available phosphorus in soil was lowest in the control, which increased with Mo application and inoculation with *Pseudomonas striata*. Available P increased significantly with increasing P levels up to 60 kg P_2O_5/ha as RP. However, the magnitude of increase was less indicating that major part of phosphorus remained in fixed form and application of phosphorus increased the amount of labile pool of phosphorus. Available phosphorus content in soil after harvest of the crop was higher in the treatment having *Pseudomonas striata* inoculation along with rockphosphate and Mo application. Similar results were also reported by Kiran Kumari and Phogat (2012). The results thus, indicate that *Pseudomonas striata* inoculation solubilizes the rockphosphate and increases the status of available phosphorus in soil (Reza *et al.,* 2012). At harvesting, the content of available K was depleted from the initial value of 100 kg/ha to 95.6 kg/ha. Available K content increased with various treatments non-significantly over the control and the maximum K content was recorded at 60 kg P_2O_5 + 2 kg Mo/ha + *P striata* inoculation. Available molybdenum was the lowest in the control (Table 4). The concentration of available molybdenum increased significantly with 2 kg Mo/ha. This increase may be ascribed to increased concentration of Mo in soil solution as a result of its addition. Application of rockphosphate also enhanced the amount of available Mo. Tripathi *et al.* (1989) also recorded increased availability of Mo with phosphorus addition. Inoculation with *P. striata* did not affect the available molybdenum status of the soil. The amount of available molybdenum was further enhanced when 2 kg Mo/ha and rockphosphate were applied together. Similarly, combined application of Mo and *P. striata* also im-

Table 4. Effect of rockphosphate, molybdenum and phosphate-solubilizing bacteria on status of available N, P, K (kg/ha) and Mo (mg/kg) in soil after harvest of crop (mean data of 2 years)

Treatment	N	P	K	Mo
Control	136	7.5	95.6	0.034
2 kg Mo/ha	144	8.8	96.0	0.061
2 kg Mo/ha + *P. striata*	146	9.8	96.2	0.065
30 kg P_2O_5/ha as RP	152	9.6	97.4	0.039
30 kg P_2O_5/ha as RP + 2 kg Mo/ha	155	10.9	98.0	0.067
30 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	160	12.3	98.8	0.070
60 kg P_2O_5/ha as RP	158	11.2	100.0	0.042
60 kg P_2O_5/ha as RP + 2 kg Mo/ha	163	12.7	100.6	0.070
60 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	166	13.6	101.0	0.074
SEm±	4.18	0.60	2.58	0.004
CD (P=0.05)	8.98	1.29	NS	0.013
Initial value	146	8.5	100	0.040

P. Striata, Pseudomonas striata; RP, rockphosphate

Table 5. Effect of rockphosphate, molybdenum and phosphate-solubilizing bacteria on economics and P use efficiency of lentil (mean data of 2 years)

Treatment	Net returns (₹/ha)	Benefit: cost ratio	Agronomic-use efficiency (kg grain/kg P applied)	Apparent P recovery (%)
Control	46,250	4.62	-	-
2 kg Mo/ha	48,750	4.06	-	-
2 kg Mo/ha + *P. striata*	51,150	4.16	-	-
30 kg P_2O_5/ha as RP	49,150	4.24	3.6	3.0
30 kg P_2O_5/ha as RP + 2 kg Mo/ ha	52,100	3.83	7.1	4.6
30 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	60,250	4.30	13.4	6.0
60 kg P_2O_5/ha as RP	52,500	3.98	3.5	5.0
60 kg P_2O_5/ha as RP + 2 kg Mo/ ha	59,950	3.94	7.7	7.3
60 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata*	63,150	4.05	8.4	9.3

P. Striata, Pseudomonas striata; RP, rockphosphate

proved the status of available molybdenum. The maximum amount of soil-available molybdenum was recorded in 60 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata* treatment.

Economics

Application of 60 kg P_2O_5/ha as RP + 2 kg Mo/ha + *P. striata* inoculation resulted in the highest net returns, followed by 30 kg P_2O_5/ha as RP + 2 kg Mo/ha + *P. striata* (Table 5). Higher yields of grain and straw directly contributed to the returns at this treatment. In 2 kg Mo/ha treatment, the returns and benefit: cost ratio were reduced due to higher cost of molybdenum fertilizer. The highest benefit: cost ratio of 4.30 was recorded with 30 kg P_2O_5/ha + 2 kg Mo/ha + *P. striata* (Table 5) and least (3.94) at 60 kg P_2O_5 + 2 kg Mo/ha treatment.

Efficiency indices

Agronomic efficiency of P was the highest (13.4 kg grain/kg P applied) with 30 kg P_2O_5/ha as RP+2 kg Mo/ha + *P. striata* inoculation, followed by 60 kg P_2O_5/ha as RP+2 kg Mo/ha + *P. striata* inoculation (Table 5). However, 60 kg P_2O_5 + 2 kg Mo/ha and 30 kg P_2O_5 + 2 kg Mo/ha treatments were at par with respect to P-use efficiency. Further increase in P (60 kg P_2O_5/ha) decreased the agronomic efficiency of P. Apparent P recovery increased with increasing level of P as rockphosphate either alone or along with *P. striata*. Apparent P recovery was the maximum (9.3 %) with 60 kg P_2O_5/ha +2 kg Mo/ha + *P. striata* and least with 30 kg P_2O_5/ha. Application of 60 kg P_2O_5 as RP increased the recovery efficiency of P over 30 kg P_2O_5/ha as RP. The effect of *P. striata on* apparent P recovery was lower than that of molybdenum and rock phosphate.

It could be concluded that combined application of 60 kg P_2O_5/ha as RP + 2 kg Mo/ha + *P. striata* inoculation is beneficial in increasing the status of available N, P and Mo in soil besides crop yield, nutrient uptake and grain quality. Use of rockphosphate at higher dose along with *Pseudomonas striata* can help to meet the P requirement of lentil crop in Agra region of Uttar Pradesh.

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