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Effect of phosphorus fertilization and microbial inoculants on yield and phosphorus use efficiency of chickpea

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Abstract
A field experiment was conducted between 2017-18 and 2018-19 to investigate the effect of different phosphorus levels (control-no P, 50% P, 75% P, 100% P and 150% P) and microbial inoculants [un-inoculated control, arbuscular mycorrhizal fungi (AM), phosphate solubilising bacteria (PSB), and AM+PSB) in chickpea-fodder maize system. Chickpea grain yields increased significantly as the rate of P application increased, with the highest yield achieved with 150 percent of the recommended P. This was comparable to 75 and 100 percent of the recommended P dose. The total P uptake by chickpea varies from 4.34–12.36 kg/ha and 4.27–12.84 kg/ha, respectively. The highest apparent recovery (AR) in both the year was recorded when 75% P was added with AM+PSB inoculation whereas, a significant reduction in AR was recorded with increase in fertilizer P beyond 75% of recommended P. Agronomic efficiency was highest under 75% P averaged across microbial inoculants in both year (16.09 kg grain/kg P). Grain yield was positively and significantly correlated with number of pods per plant (0.98 and 0.99 in first and second year individually), grain weight per plant (0.91 and 0.92 in first and second year separately) and test weight (0.93 and 0.95 in first and second year separately). Grain yield was likewise positively and significantly correlated with total uptake of phosphorus (0.94 and 0.96) in both the year.

Keywords: Phosphorus, fertilization, microbial, phosphorus, chickpea

Introduction

Phosphorus is referred as the “king-pin” in Indian agriculture. Neither plant nor animal can live without phosphorus. It is an essential component of the organic compound adenosine triphosphate (ATP), which is the “energy currency” that drives most of the biochemical processes. Phosphorus (P) is one of 17 nutrient elements, essential for the growth and development of plants and second only to nitrogen in its impact on the productivity and health of terrestrial and aquatic ecosystem. In plants, it plays a vital role virtually in all biochemical processes that involve energy transfer. Cell division and development, breakdown of sugars, photosynthesis, and nutrient transfer within the plant and gene expression are the Key functions of phosphorus in plants (Mahdi *et al.*, 2011) [3]. Phosphorus is important constituent of deoxyribonucleic acid (DNA), the seat of genetic inheritance, and of ribonucleic acid (RNA), which direct protein synthesis in both plants and animals. Low availability of P in soil due to high fixation and slow diffusion is a limiting factor in crop production. Therefore, phosphorus supply throughout crop growth period and optimum yield can only be achieved after judicious use of P fertilizers.

Materials and Methods

The field experiment was conducted during 2017-18 and 2018-19 with Chickpea-Fodder Maize cropping system at the Instructional Farm of DKS, College of Agriculture and Research Station, Bhatapara, Chhattisgrah. The experimental soil was clay loam, neutral to alkaline in reaction, low in organic carbon (0.3%), low in available N (112.8 kg ha^{-1}), medium in available P (12.74 kg ha^{-1}) and high in available K (385 kg ha^{-1}). Twenty treatment combinations comprising four bio fertilizer levels [un-inoculated control, arbuscular mycorrhizal fungi (AM), phosphate solubilising bacteria (PSB) and AM+PSB] as main plot treatment and five levels of phosphorus (control, 50% P, 75% P, 100% P. and 150% P) as sub plot treatment in split plot design with three replication. Soil test based recommended dose of NPK (20:60:20 kg ha^{-1}) were applied through urea, diammonium phosphate and muriate of potash, respectively. Fertilizer N and K were applied uniformly to all the plots, whereas P was applied as per treatments. For microbial inoculation, AM culture (25 kg/ha) was applied in furrows at the time of sowing. Seeds were treated with PSB culture, and dried in shade before sowing in the respective treatments.

Soil samples were collected from rhizosphere (0-15 cm) at flowering and harvest stage of chickpea. Available P (Olsen P) was extracted using 0.5 M $NaHCO_3$ (pH 8.5) according to Olsen *et al*. (1954). The representative plant samples (grain and straw) collected from each plot during the crop cycle were processed as per standard procedures. The processed plant samples were digested in a di-acid mixture (HNO_3: $HClO_4$ in ratio of 4:1) and total P in the digested extracts was determined colorimetrically by vanadomolybdo-phosphate yellow color method. Phosphorus uptake, apparent recovery (AR), agronomic efficiency (AE) and partial factor productivity were computed as:

Phosphorus uptake seed (kg ha^{-1}) = concentration in seed (%) × seed yield (q ha^{-1})

Phosphorus uptake straw/sover (kg ha^{-1}) = concentration in straw/sover (%) × straw/stover yield (q ha^{-1})

1. Agronomic efficiency (kg grain kg $^{-1}$P) = [{Grain yield (t ha^{-1}) under P treatment - Grain yield (t ha^{-1}) under no P treatment} ÷ Rate of P application (kg ha^{-1})] × 1000
2. Apparent recovery of P (%) = [{Total P uptake (kg ha^{-1}) in P treated plot - Total P uptake (kg ha^{-1}) in no P treated plot} ÷ Rate of P application (kg ha^{-1})] × 100
3. Partial factor productivity = Y/Nr (Where, Y is the yield in kg ha^{-1} and Nr is the amount of fertilizer nutrient applied in kg ha^{-1}).

Results and Discussion

Grain and straw yield

It is apparent from the data presented in table 1 that inoculation of bio fertilizer showed significant effect on grain yield in both the year and pooled data. The maximum grain yield recorded by AM+PSB was 21.43, 23.33 and 22.38 q ha^{-1} during both the year and pooled data, which was significantly increased over un-inoculated control (16.36, 17.44 and 16.90 q ha^{-1} during both the year and pooled data, respectively). Seed inoculation with PSB alone (20.28, 22.41 and 21.34 q ha^{-1} during both the year and pooled data, respectively) was also observed to be statistically equal, though higher than that of inoculation of AM alone (18.60, 19.44 and 19.02 q ha^{-1} during both the year and pooled data, respectively).With each gradual rise in phosphorus levels up to 150 percent of the recommended dose of phosphorus, grain yield increased significantly (Table 1). The application of 150 percent of recommended dose of phosphorus resulted in the highest grain yield (22.60, 24.64 and 23.62 q ha^{-1} during both the year and pooled data, respectively). However, it was statistically equivalent to 75% (20.14, 21.65, and 20.90 q ha^{-1}during both the year and pooled data, respectively) and 100% (22.04, 23.65, and 22.84 q ha^{-1}during both the year and pooled data, respectively) of the recommended phosphorus dose. It was also observed that applying 75 and 100 percent of the recommended phosphorus dose was statistically equivalent in terms of grain yield, but superior to control and 50 percent of the recommended dose of phosphorus.

As per the perusal of data in table 4.9 revealed that grain yield of chickpea was significantly influenced by the interaction effect between bio inoculants and phosphorus levels. The maximum grain yield was obtained with the combination of 150 per cent of recommended dose of phosphorus and dual inoculation of AM+PSB (23.20 and 27.27 q ha^{-1} during first and second year, respectively), which was at par with the combination of 100 per cent recommended phosphorus and AM+PSB inoculation to chickpea (22.42 26.38 q ha^{-1} during first and second year, respectively).

Straw yield

Inoculation of bio fertilizer significantly influenced the straw yield. Among the inoculation of bio fertilizer AM+PSB produced significantly higher straw yield (37.45, 38.45 and 37.95 q ha^{-1} during both the year and pooled data, respectively) than un-inoculated control (29.39, 31.42 and 30.41q ha^{-1} during both the year and pooled data, respectively) and sole inoculation with AM (31.43, 33.48 and 32.46 q ha^{-1} during both the year and pooled data, respectively) and PSB (33.38, 34.41 and 33.90 q ha^{-1} during both the year and pooled data, respectively). Phosphorus application significantly increased straw yield up to 150 percent of the recommended phosphorus dose (36.92, 38.42 and 37.67 q ha^{-1} during both the year and pooled data, respectively). However, it was statistically equivalent to the 75 percent (33.94 and 35.44 q ha^{-1} in the first and second years, respectively) and 100 percent (35.91 and 37.43 q ha^{-1} in the first and second years, respectively) phosphorus recommendations. During both the years and pooled data, 75 and 100 per cent of the recommended dose of phosphorus were found to be statistically equal, but superior to control and 50 percent of the recommended dose of phosphorus.

The increase in yield with P application may be attributed to a general improvement in plant growth, as P plays an important role in root development, energy translocation, and metabolic processes in the plant, all of which contribute to higher yield. These results are in conformity with those of Singh *et al*. (2014), Pramanik and Singh (2003) [6], Naagar and Meena (2004) [5] and Kumar *et al*. (2008).

Phosphorus uptake (kg ha^{-1})

Data presented in table 2 revealed that microbial inoculation had significant influence on phosphorus uptake. Dual inoculation with AM+PSB registered significantly higher total phosphorus uptake (11.51, 12.04 and 11.77 kg ha^{-1} during both the year and pooled data, respectively) compared to un-inoculated control (4.91, 5.07 and 4.99 kg ha^{-1} during both the year and pooled data, respectively). Due to varying phosphorus levels, total phosphorus uptake varied significantly (Table 2). The highest total phosphorus uptake (12.36, 12.84, and 12.60 kg ha^{-1} during both the year and pooled data, respectively) was linked to 150 percent of the recommended dose of phosphorus, followed by 100 percent of the recommended phosphorus dose (11.25, 11.61, and 11.43 kg ha^{-1} during both the year and pooled data, respectively), and was significantly superior to control (4.34, 4.27 and 4.31 kg ha^{-1} during both the year and pooled data, respectively).

Interaction effect between microbial inoculants and phosphorus levels were found to be significant on phosphorus uptake by seed and total phosphorus uptake by chickpea (Table 2). Highest uptake by seed and total P was obtained from the combination of dual inoculation of AM+PSB with 100 per cent recommended dose of phosphorus. This combination was at par with the combination of dual inoculation of AM+PSB with 75 per cent recommended dose of phosphorus. Lowest phosphorus uptake was recorded at control which was significantly lower than rest of the combinations.

PSB might have helped in reducing P fixation by its chelating effect and also solubilized the unavailable form of phosphorus leading to more uptakes of nutrients. Crop inoculation with AM and PSB improved nutrient absorption and utilization, resulting in increased N and P content in seed and straw. Microbial inoculation aids in the release of phosphorus from native sources while also protecting the fixation of added phosphorus, resulting in more available phosphorus for the plant, resulting in improved nutrient content and uptake. These results are in close conformity with the findings of Meena *et al*. (2004) [5]. Increased phosphorus uptake with higher phosphorus levels may be due to a better nutritional environment in the rhizosphere as well as in the plant system, resulting in increased P translocation, especially to reproductive structures. Since uptake is the function of seed and straw yield as well as their nutrient content, the significant increase in content of the nutrients coupled with increased seed and straw yield increased the uptake of P substantially. The results are in line with the findings of Das *et al*. (2013) and Pramanik and Singh (2003) [1, 6].

Phosphorus use efficiency

Apparent Recovery of Phosphorus

Increasing level of phosphorus diminished apparent phosphorus recovery during both the year, most elevated being recorded at 75 per cent recommended dose of phosphorus with combined inoculation of AM+PSB (Table 3). This may be due to solubilization and mobilization of native and applied phosphorus by AM and PSB, thus resulting in higher uptake by chickpea. With increase in higher phosphorus level beyond 75% of recommended P, there was decrease in AR. This might be clarified in terms of the fact that plants being grown in a given soil, shown greater competition for nutrient absorption at lower dose. Comparable outcome was accounted for by Pramanik and Singh (2003) [6].

Agronomic Use Efficiency

Table 3 showed that 75 percent of the recommended phosphorus dose in combination of dual microbial inoculation was used, with the most notable phosphorus use efficiency. In both years, increasing the amount of added phosphorus reduced the efficiency of phosphorus usage. Kumaw at *et al*., (2018) [2] also reported that 50% of recommended dose of P with AM+PSB gave the highest total P uptake (26.6), apparent recovery (28.2%) and agronomic efficiency (51.2 kg grain/kg P applied) in maize.

Partial factor productivity

Phosphorus partial factor productivity was highest at 50 percent of the recommended dose of phosphorus (58.21 and 62.31 kg grain/kg P absorbed). Further increases in phosphorus levels reduced production efficiency in both years (Table 3). Despite increased phosphorus concentration in grain and straw with increased grain and straw yield, partial factor productivity showed that the consumed phosphorus was not efficiently used for grain development at higher levels of phosphorus application as it was used at lower level. Such perception was likewise made by Das *et al*. (2013) [1].

Correlation between Yield with yield attributes and total uptake of N and P: On perusal of the upsides of coefficient of correlation introduced in table 4 uncovered that seed yield was positively and significantly correlated with different yield attributing characters. Grain yield was positively and significantly correlated with number of pods per plant (0.98 and 0.99 in first and second year individually), grain weight per plant (0.91 and 0.92 in first and second year separately) and test weight (0.93 and 0.95 in first and second year separately). Grain yield was likewise positively and significantly correlated with total uptake of nitrogen and phosphorus in both the year.

Table 1: Effect of P fertilization and microbial inoculants on grain, straw and biological yield of Chickpea

Treatments	Grain yield (q/ha)			Straw yield (q/ha)			Biological yield (q/ha)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Level of bio fertilizers									
B1 (Control)	16.36	17.44	16.90	29.39	31.42	30.41	45.75	48.86	47.31
B2 (AM)	18.60	19.44	19.02	31.43	33.48	32.46	50.03	52.91	51.47
B3 (PSB)	20.28	22.41	21.34	33.38	34.41	33.90	53.66	56.82	55.24
B4 (AM+PSB)	21.43	23.33	22.38	37.45	38.45	37.95	58.88	61.79	60.33
SE (m) ±	0.52	0.97	0.56	0.73	0.58	0.38	0.70	0.34	0.63
CD (0.05)	2.22	4.11	1.98	3.11	2.47	1.34	2.98	1.43	2.23
Level of phosphorus									
F1 (No P)	13.60	14.63	14.12	26.84	28.48	27.66	40.44	43.11	41.78
F2 (50% P)	17.46	18.69	18.08	30.95	32.44	31.70	48.41	51.13	49.77
F3 (75% P)	20.14	21.65	20.90	33.94	35.44	34.69	54.08	57.10	55.59
F4 (100% P)	22.04	23.65	22.84	35.91	37.43	36.67	57.95	61.07	59.52
F5 (150% P)	22.60	24.64	23.62	36.92	38.42	37.67	59.52	63.06	61.29
SE (m) ±	0.68	0.62	0.45	0.76	0.74	0.63	1.17	1.04	0.82
CD (0.05)	1.97	1.79	1.30	2.18	2.14	1.83	3.36	3.01	2.39
Interaction CD (0.05)	3.98	3.62	2.96	NS	NS	NS	NS	NS	NS

Table 2: Effect of phosphorus fertilization and microbial inoculants on phosphorus uptake of chickpea at harvest

Treatments	Phosphorus (kg ha^{-1})								
	Seed			Straw			Total		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Level of bio fertilizers									
B1 (Control)	3.44	3.66	3.55	1.47	1.57	1.52	4.91	5.07	4.99
B2 (AM)	5.95	6.03	5.99	2.20	2.34	2.27	8.15	8.26	8.21

B3 (PSB)	6.89	8.07	7.48	2.67	2.75	2.71	9.57	10.19	9.88
B4 (AM+PSB)	8.14	9.10	8.62	3.37	3.46	3.42	11.51	12.04	11.77
SE (m) ±	0.21	0.55	0.27	0.34	0.41	0.32	0.23	0.67	0.42
CD (0.05)	0.90	2.31	0.77	1.43	1.74	1.13	0.76	2.83	1.50
Level of phosphorus									
F1 (No P)	3.26	3.07	3.17	1.07	1.14	1.11	4.34	4.27	4.31
F2 (50% P)	5.41	5.42	5.42	1.86	1.95	1.90	7.27	7.32	7.29
F3 (75% P)	7.25	7.36	7.31	2.38	2.48	2.43	9.63	9.73	9.68
F4 (100% P)	8.37	8.99	8.68	2.87	2.99	2.93	11.25	11.61	11.43
F5 (150% P)	9.04	9.86	9.45	3.32	3.46	3.39	12.36	12.84	12.60
SE (m) ±	0.26	0.34	0.17	0.20	0.50	0.26	0.30	0.56	0.31
CD (0.05)	0.74	0.97	0.51	0.57	1.43	0.75	0.87	1.62	0.91
Interaction CD (0.05)	1.37	1.58	1.41	NS	NS	NS	1.75	3.28	NS

Table 3: Phosphorus use efficiency in chickpea as affected by phosphorus fertilization and microbial inoculants

Treatments	Phosphorus Use efficiency					
	AR (%)		AUE		PFP	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Level of bio fertilizers						
B1 (Control)	-	-	-	-	-	-
B2 (AM)	20.61	23.25	11.09	11.42	32.94	34.42
B3 (PSB)	21.30	24.73	13.95	12.67	36.72	39.53
B4 (AM+PSB)	22.16	24.89	14.23	13.11	38.05	41.14
Level of phosphorus						
F1 (No P)	0.00	0.00	0.00	0.00	0.00	0.00
F2 (50% P)	26.23	31.38	15.13	14.37	58.21	62.31
F3 (75% P)	28.64	33.22	16.03	16.16	44.75	48.12
F4 (100% P)	26.17	28.23	15.19	15.44	36.73	39.41
F5 (150% P)	22.42	25.90	12.89	13.68	30.13	32.86

Table 4: Coefficient of correlation between Yield with yield attributes and total uptake of N and P as affected by phosphorus fertilization and microbial inoculants

Yield	No. of pods/plant	Grain weight/plant	Test weight	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})
Seed yield 2017	0.98**	0.91**	0.93**	0.94**	0.94**
Seed yield 2018	0.99**	0.92**	0.95**	0.95**	0.96**

Optimum economic dose of phosphorus for chickpea

Response of chickpea seed yield for different dose of phosphorus was determined by taking into consideration the two year mean seed yield as affected by different doses of phosphorus. The crop responded quadratically to application of phosphorus. The optimum dose worked out was 50 kg P_2O_5/ha for chickpea.

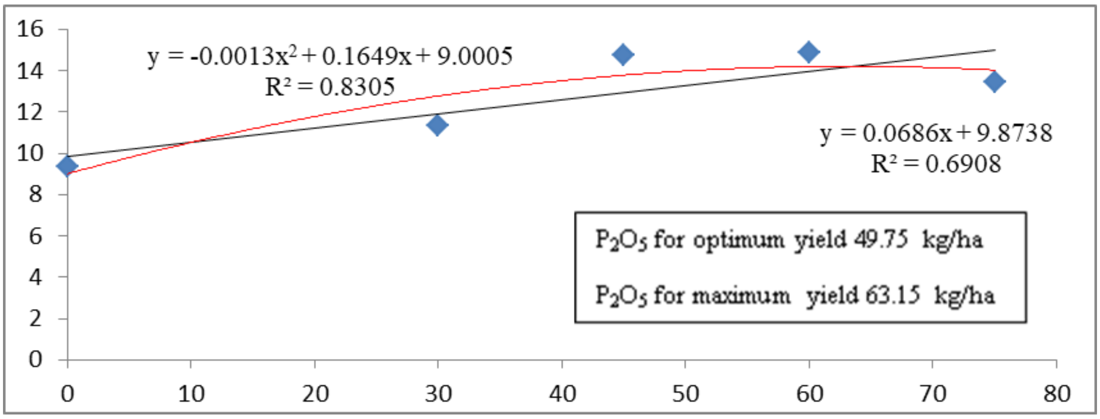

Fig 1: Response curve of phosphorus applied to chickpea

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