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The influence of different phosphorus solubilizing Bacteria doses and application methods, as well as Phosphorus levels, on Phosphorus content and uptake in sunflower and chickpea at various growth stages

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Abstract
A field experiment was conducted to study the effect of different doses and method of phosphate solubilizing bacteria (PSB) application and the Phosphorus (P) levels on sunflower and chickpea during *Rabi,* 2020 at College of Agriculture, PJTSAU, Rajendranagar, Hyderabad. The experiment was laid out in Randomized Block Design, comprising eleven treatments with three replications. Phosphate solubilizing bacteria was applied to soils with two different methods; 1) Soil application of lignite based powder form with two doses (3kg and 6kg per hectare) after mixing with vermicompost @ 1t/ha. This mixture was applied in sowing line. This source of PSB had 10^8 -10^9 viable colony counts per gram of PSB. 2) Soil application of liquid PSB biofertilizer with 50mL/L (8L per hectare) by drenching in the sowing line. The application of the NPK fertilizer as per the recommended dose of the sunflower and chickpea. The results showed that the effect of PSB and P levels on P uptake by shoot at different growth stages and seed at harvest of sunflower and chickpea had a significant effect and there was an increase in P uptake with the age of the crop. Among all the treatments, in sunflower highest P uptake was recorded in Treatment with 75% P application and soil application of PSB @ 6 kg/ha and lowest was recorded with No P level. whereas in chickpea, P uptake by shoot of chickpea was recorded highest with 50% P +PSB-SA2.

Keywords: Phosphorus solubilizing bacteria, phosphorus uptake, drenching, soil application

Introduction

Sunflower (*Helianthus annus* L.) is a member of the Asteraceae family and has significant design capacity, as seen by the formation of heads that vary in size and color from cream to yellow in different cultivars. It is a potential source of high-quality edible oil and ranks second only to soybean as an oil crop in the world (FAO). As of January 2016, the total world area under sunflower was 24.7 million hectares, with an average yield of 1.67 tons per hectare (NSA, 2016). Since the introduction of this crop in India in the 1970s, productivity has remained low in comparison to global average productivity, despite a significant increase in crop area (Krishnamurthy *et al*. 2011) [5]. Sunflower seeds contain 48% to 52% of high-quality edible. The global sunflower seed, oil and meal productions in the year 2018-19 was estimated at 51.41 mt, 19.45 mt and 20.90 mt.

Chickpea (*Cicer arietinum* L.) is a multipurpose pulse crop consumed by the people in different forms. Chickpea is one of the major Rabi pulse crop. Among, the pulses chickpea is known as "King of pulses'. It ranks third among leguminous crops after pea (*Pisum sativum* L.) and beans (*Phaseolus vulgaris* L.). In India, it occupies about 9.18 million hectare area with production of 8.22 million tones and an average productivity of 900 kg ha^{-1} (Anonymous, 2013). In India 2017-18, chickpea was cultivated in about 106 lakh hectare and productivity of 1056 kg ha^{-1}. In Telangana the area contributed for chickpea cultivation was 1.03 lakh hectare and production of 1.50 lakh tones. Amongst the leguminous crops, Chickpea occupies an important position due to its nutritious value (17-23% protein) in large vegetarian population of the country.

Phosphorus fertilization to legumes is more important than that of nitrogen. The cultivation of pulses without phosphatic fertilizer is one of the important factors responsible for their low productivity. Phosphorus nutrient in legumes simulates a greater attention in increasing the productivity, as it encourages healthy root growth and promotes rhizobia activity resulting in increased nodulation that exemplify nitrogen fixation. Phosphorus plays a vital functional role in energy transfer and metabolic regulation and it is an important structural component of many molecules.

Phosphate solubilizing bacteria (PSB) play an important role in enhancing phosphorus availability to plants by lowering soil pH and by microbial production of organic acids and mineralization of organic phosphorus. Introduction of PSB in the rhizosphere of crop also increases the efficiency of phosphatic fertilizers (Gaur, 1990) [2]. Thus, adopting proper nutrient management practices in conjunction with PSB will help to improve the yield and quality of crop besides maintaining the soil fertility (Singh and Singh, 2012) [8]. PSB have been widely used as inoculants to increase crop yield by solubilizing insoluble P in soils.

Materials and Methods

The experiment was conducted during *Rabi*, 2020 and the geographical location of the experimental site was 17° 32' N Latitude, 78° 40' E Longitude with an altitude of 477 m above mean sea level. Agro-climatologically the area is classified as Southern Telangana Agro Climatic Zone of Telangana state.

The field was sandy loam in texture, alkaline in soil reaction, non - saline, low in O.C and available nitrogen, medium status of available phosphorus, available potassium and available sulphur. The experiment was laid out in RBD comprising eleven treatments with three replications. The experimental details is given in below table.

Table 1: Experimental details

Technical details	Experiment
Season	Rabi, 2020
Design	Simple RBD
Replication	03
Treatments	11
Variety	Sunflower (KBSH-78) Chickpea (NBeG-252)
Seed rate	8-10kg/ha(Sunflower) 60 kg/ha (Chickpea)
Spacing	60X30cm(Sunflower) 30X10 cm (chickpea)
Duration	93-98 days (Sunflower and chickpea)
RDF	60:90:30NPKKgha-1. (Sunflower) 30:60:0 NPK Kg ha-^{1}. (Chickpea)
Gross plot size	4.8m x 3 m
Net plot size	3.6m X 2.4 m

Table 2: Treatment details

Treatment	Treatment detail
T_1	100% NPK, (RDF)
T_2	No P
T_3	No P + PSB-D
T_4	No P +PSB-SA_1
T_5	No P + PSB-SA_2
T_6	75% P + PSB-D
T_7	75% P+ PSB-SA_1
T_8	75% P + PSB-SA_2
T_9	50% P + PSB-D
T_{10}	50% P+ PSB-SA_1
T_{11}	50% P + PSB-SA_2

D = Drenching @ 50 ml L^{-1} or 8 L ha^{-1}.
SA_1 = Soil application of PSB @ 3 kg ha^{-1}
SA_2 = Soil application of PSB @ 6 kg ha^{-1}

To sunflower (KBSH-78) hybrid RDF of 60:90:30 kg ha^{-1} NPK and for chickpea 30:60:0 NPK Kg ha-^{1}. was applied. Uniform dose of N and K was applied to all the treatment. While Phosphorus was applied as per the treatments given in Table 2. PSB was applied as soil application and drenching at the time of sowing. Lignite based powder form with two doses @ 3 and 6 kg per hectare was properly mixed with vermicompost @ 1 t ha^{-1} was applied to soil in the sowing line. The liquid PSB @ 8 L per hectare was drenched in the sowing line.

Results and Discussion

Sunflower

Shoot P content (%): Phosphorus content in the sunflower shoot at different crop growth stages and also seed is furnished in the Table 3 and depicted by the bar chart in Figure 1. From the results, it was also seen that the Phosphorus content of the sunflower gradually decreased from flower initiation stage to maturity stage. Intersentingly, the highest phosphorus content in all the growth stages was reported in T_8 (i.e.,75% P+ PSB @ SA2 and the lowest phosphorus content noticed in control T_2 *i.e.*, No P.

Seed P content (%)

After harvest, the phosphorus content of seed varied from 0.57% to 0.27% with the treatments 75% P + PSB-SA_2 and control. Highest Phosphorus content was obtained in T_8 (0.57%) with 75% P+PSB @ SA_2 which was significant against the T_1 (0.50%) *i.e.*, 100% NPK and also par with T_7 (0.55%) *i.e.*, 75% P + PSB-SA_1. P plays a very important role in photosynthesis as it is crucial for activation of ribulose-1, 5 - bisphosphate carboxylase oxygenase (Rubisco) and in providing phosphorylated intermediates of calvin cycle. P application seems to increase oil yield per unit area through the increase in seed yield without reduction in percent oil due to dilution with increase in yield. This study also indicate that P is recommended to increase oil percentage. (Salih, 2013) [6]

Improvement in population of PSB as recorded was due to application of bacterial source together with lower levels of P fertilization compared to the other treatments. Kaur *et al.* (2015) [4] has reported that PSB inoculation along with RP fertilization increases the PSB population and the amount of plant-available P in the rhizosphere soil. The combined use of PSB and P fertilization was more economical in terms of crop yield, and it was also a sustainable crop production technology. Thus, this approach could reduce over application of P levels and profit farmers and environmental friendly practice. These was also supported by findings of (Sundara *et al.*, 2002) [9].

Table 3: Effect of different doses and methods of PSB application and P levels on phosphorus content (%) in sunflower at different growth stages and in the seed at maturity stage

Treatment	Treatment detail	Shoot P content (%)			Seed P (%)
		Flower Initiation	Grain filling	Maturity	
T-1	100% NPK, (RDF)	0.72	0.61	0.28	0.50
T-2	No P	0.47	0.50	0.24	0.27
T-3	No P + PSB-D	0.56	0.52	0.26	0.37
T-4	No P +PSB-SA1	0.62	0.53	0.27	0.46
T-5	No P + PSB-SA2	0.68	0.56	0.27	0.47
T-6	75% P + PSB-D	0.76	0.66	0.29	0.53
T-7	75% P+ PSB-SA1	0.79	0.67	0.30	0.55
T-8	75% P + PSB-SA2	0.80	0.67	0.33	0.57
T-9	50% P + PSB-D	0.72	0.58	0.28	0.47
T-10	50% P+ PSB-SA1	0.73	0.61	0.29	0.50
T-11	50% P + PSB-SA2	0.75	0.64	0.29	0.50
	SEM± CD (0.05) CV%	0.02	0.02	0.01	0.01
		0.07	0.05	0.03	0.04
		5.54	5.09	6.05	5.21

Chickpea

Shoot P content (%)

Phosphorus content in shoot and seed at different growth stages has been reported in Table 2 and depicted in Fig 2. From the results, the phosphorus content decreased in shoot from flower initiation to maturity stage. The highest phosphorus content at all stages was reported in T_{11}, i.e., 50% P+ PSB @ SA2 and lowest phosphorus content at all stages was reported in T_2, i.e., No P. The P content was highest in shoot at flower initiation stage and there after it declined in pod filling stage and further declined in shoot at maturity stage of the plants. This indicates the maximum activity of plants at flower initiation stage had acquired more P in shoot and at harvesting this acquired P moved towards sink or reproductive portion.

Seed phosphorus (%): At maturity stage, phosphorus concentration varied from 0.39% to 0.54% in the treatment, control and 50% P + PSB-SA2 respectively. There was a significant increase in phosphorus content in T_{11} against the T_1 as shown in Table 2. Phosphorus content of grain and straw of chickpea increased significantly with increasing doses of P which may be attributes to better root growth due to phosphorus, resulting in higher content of P in the crop. These results were in collobaration with the findings of Singh *et al.* (2012) [8].

Table 4: Effect of different doses and methods of PSB application and P levels on phosphorus content (%) in chickpea at different growth stages and in the seed at maturity stage

Treatment	Treatment detail	Shoot P content (%)			Seed P (%)
		Flower initiation	Pod filling	Maturity	
T-1	100% NPK, (RDF)	0.74	0.58	0.28	0.48
T-2	No P	0.59	0.40	0.22	0.39
T-3	No P + PSB-D	0.62	0.49	0.23	0.41
T-4	No P +PSB-SA1	0.63	0.53	0.24	0.43
T-5	No P + PSB-SA2	0.65	0.55	0.25	0.44
T-6	75% P + PSB-D	0.72	0.56	0.24	0.45
T-7	75% P+ PSB-SA1	0.73	0.57	0.28	0.46
T-8	75% P + PSB-SA2	0.75	0.58	0.29	0.49
T-9	50% P + PSB-D	0.75	0.59	0.29	0.50
T-10	50% P+ PSB-SA1	0.76	0.60	0.30	0.52
T-11	50% P + PSB-SA2	0.76	0.63	0.31	0.54
	SEM± CD (0.05) CV%	0.02	0.02	0.01	0.01
		0.06	0.05	0.04	0.04
		5.19	5.32	9.03	5.34

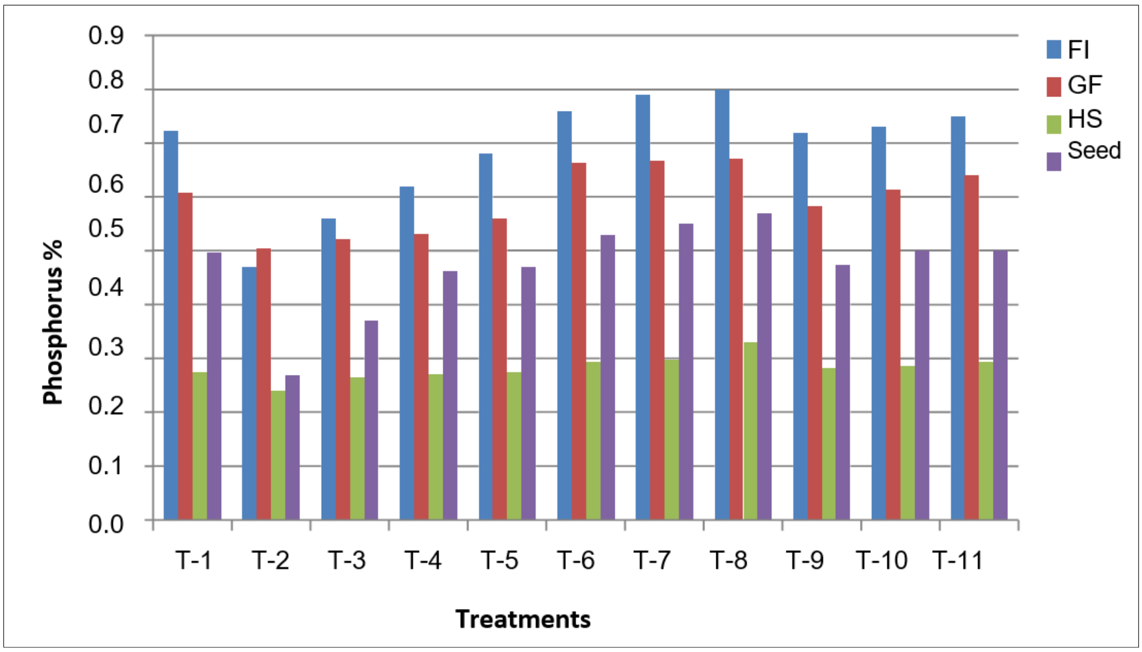

Fig 1: Sunflower phosphorus content (%) in shoot at different growth stages and seed as influenced by doses and methods of PSB application, and levels of phosphorus.

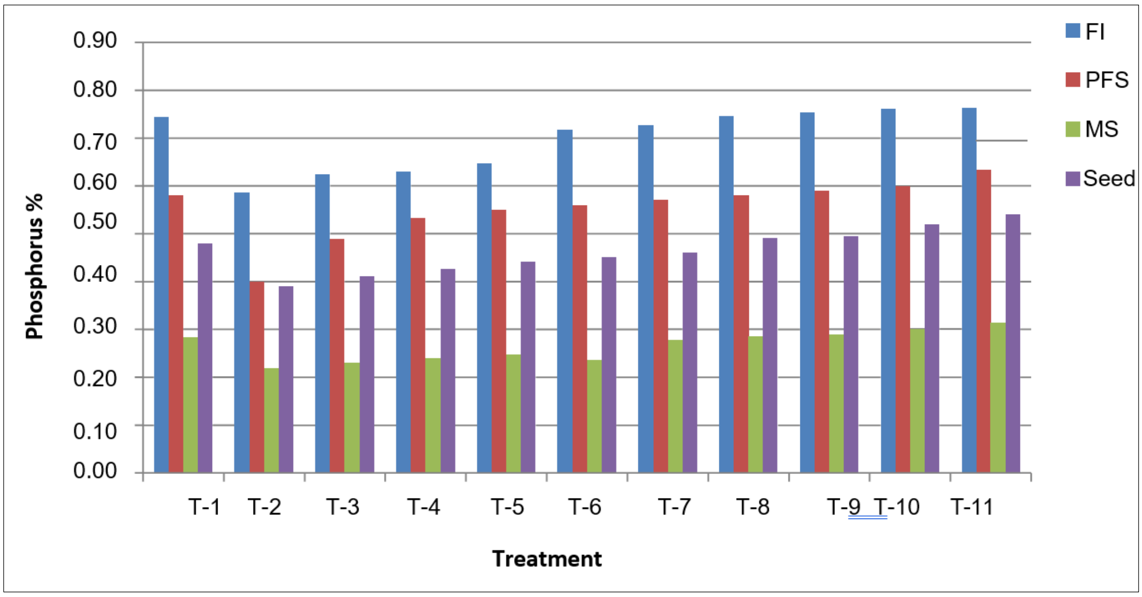

Fig 2: Chickpea phosphorus content (%) in shoot at different growth stages and seed as influenced by doses and methods of PSB application, and levels of phosphorus.

Effect of different doses and methods of PSB application and P levels on phosphorus uptake of sunflower and chickpea during different growth stages

Sunflower

Shoot P uptake (kg ha^{-1})

The phosphorus uptake by sunflower shoot increased from flower initiation stage to grain filling stage. At this stage maximum uptake of phosphorus was seen compared to flower initiation stage and harvesting stage. There was an increase in P uptake with application of PSB as with both soil application and drenching. Maximum uptake of phosphorus (13.74 kg ha^{-1}) was seen in T_8, which had received levels, 75% P, + PSB- SA2 which was on par with the T_7 (12.86), 75% P + PSB –SA_1). After the harvest of the crop, there was a decrease in P uptake by the shoot. Among the treatments, the treatment with, 75% P + PSB – SA_2 recorded highest in phosphorus uptake (7.27 kg ha^{-1}) followed by T_7 (6.20 kg ha^{-1}), 75% P, + PSB – SA_1.

Uptake being a function of nutrient concentration and dry matter production, it increased with advancement of crop growth. From flower initiation to harvest P content decline due to dilution effect, caused by higher dry matter production compared to absorption and mobilization of P towards sink. The solubilizing action of organic acids produced by PSB through decomposition of FYM would have enhanced the release of native P, stimulated growth of microorganisms in soil, and better root growth together with better mineralization of organic P and inorganic P applied initially was reported by Senthilvalavan, (2018) [7].

Seed P uptake (kg ha^{-1})

After the harvest, the phosphorus uptake of seed varied from (4.41 to13.54 kg ha^{-1}). The highest P uptake was seen in T_8

(13.59kg ha^{-1}) with the application of phosphorus levels 75% P + PSB – SA2 followed by T_7 (12.73 kg ha^{-1}) which was at par to each other. There was a significant increase in P uptake by seed with the control T_1 *i.e.*, 100% NPK. The lowest P uptake was seen in T_2 (4.41 kg ha^{-1}) with No P

Table 5: Effect of different doses and methods of PSB application and P levels on P uptake by shoot during different growth stages and seed at harvest of sunflower

Treatment	Treatment detail	Shoot phosphorus uptake (kg ha^{-1})			Seed P uptake (kg ha^{-1})
		Flower initiation	Grain filling	Maturity	
T-1	100% NPK, (RDF)	10.76	10.75	5.30	9.69
T-2	No P	5.82	7.90	3.82	4.41
T-3	No P + PSB-D	7.14	8.37	4.45	6.40
T-4	No P +PSB-SA1	8.05	8.74	4.80	8.10
T-5	No P + PSB-SA2	9.39	9.51	5.01	8.82
T-6	75% P + PSB-D	12.16	12.61	6.01	11.05
T-7	75% P+ PSB-SA1	13.16	12.86	6.20	12.73
T-8	75% P + PSB-SA2	14.08	13.74	7.27	13.59
T-9	50% P + PSB-D	10.17	10.19	5.29	9.12
T-10	50% P+ PSB-SA1	11.05	11.19	5.62	9.84
T-11	50% P + PSB-SA2	11.68	11.95	5.93	10.14
	SEM±	0.55	0.33	0.22	0.57
	CD (0.05)	1.62	0.98	0.65	1.69
	CV%	9.25	5.38	5.93	10.51

Chickpea

Shoot P uptake (kg ha^{-1})

From the data, presented in Table 4.14, it was noticed there was an increase in P uptake from flower initiation stage to pod filling stage. There was a significant increase with P levels up to 50% P level. Among all the treatments, highest P uptake was seen in T_{11} (15.84 kg ha^{-1}) *i.e.*, 50% P +PSB – SA2 followed by T_{10} (14.71 kg/ha) *i.e.*, 50% P + PSB – SA1, which were at par to each other and lowest was seen in T_2 (4.33 kg/ha) *i.e.*, No P.

At maturity stage, the P uptake varied from (2.26 to 5.1 kg ha^{-1}) as shown in Fig 4.10. Highest P uptake was seen in T_{11} (5.1 kg ha^{-1}) *i.e.*, 50% P, + PSB – SA2 followed by T_{10} (5) *i.e.*, 50% P +PSB –SA1 which was at par to each other.

PSB inoculation positively affected the P uptake and consequently, increased the shoot P content significantly with respect to uninoculated control plants. The enhanced P uptake caused by PSB inoculation allowed the plants to utilize P from fixed resources. The results were in accordance with Gull *et al* (2004) [3]. Arya *et al*. (2007) [1] reported that significantly maximum P uptake was observed with application of 50% recommended dose of chemical levels (20 kg N and 40 kg P ha $^{-1}$) + FYM at 5 t ha + PSB.

Seed P uptake (kg ha^{-1})

After the harvest, the seed P uptake of chickpea varied from 3.27 to 8.06 kg ha-1.There was a significant increase in P uptake by the seed with 50% phosphorus levels along with PSB application. Highest P uptake was seen in T_{11} (8.06 kg ha^{-1}) *i.e.*, 50% P+ PSB –SA2 and lowest phosphorus uptake was noticed in T_2 (3.27 kg ha^{-1}) *i.e.*, No P. The seed P uptake with T_{10} which had applied with 50% P (100% NK) + PSB-3 was on par with the T_{11}.

Table 6: Effect of different doses and methods of PSB application and P levels on P uptake by shoot during different growth stages and seed at harvest of chickpea.

Treatment	Treatment detail	Shoot P uptake (kg ha^{-1})			Seed P uptake (kg ha^{-1})
		Flower initiation	Pod filling	Maturity	
T-1	100% NPK, (RDF)	11.73	11.02	5.05	5.84
T-2	No P	4.87	4.33	2.26	3.27
T-3	No P + PSB-D	6.59	5.79	2.90	3.82
T-4	No P +PSB-SA1	7.26	6.56	3.25	4.20
T-5	No P + PSB-SA2	8.50	8.70	3.75	4.48
T-6	75% P + PSB-D	10.02	10.17	3.77	4.75
T-7	75% P+ PSB-SA1	10.48	10.34	4.53	5.08
T-8	75% P + PSB-SA2	12.96	12.12	4.8	5.97
T-9	50% P + PSB-D	13.94	12.86	4.9	6.50
T-10	50% P+ PSB-SA1	14.23	14.71	5	7.39
T-11	50% P + PSB-SA2	15.18	15.84	5.1	8.06
	SEM±	0.45	0.69	0.23	0.30
	CD (0.05)	1.33	2.04	0.69	0.90
	CV%	7.44	11.76	8.50	9.82

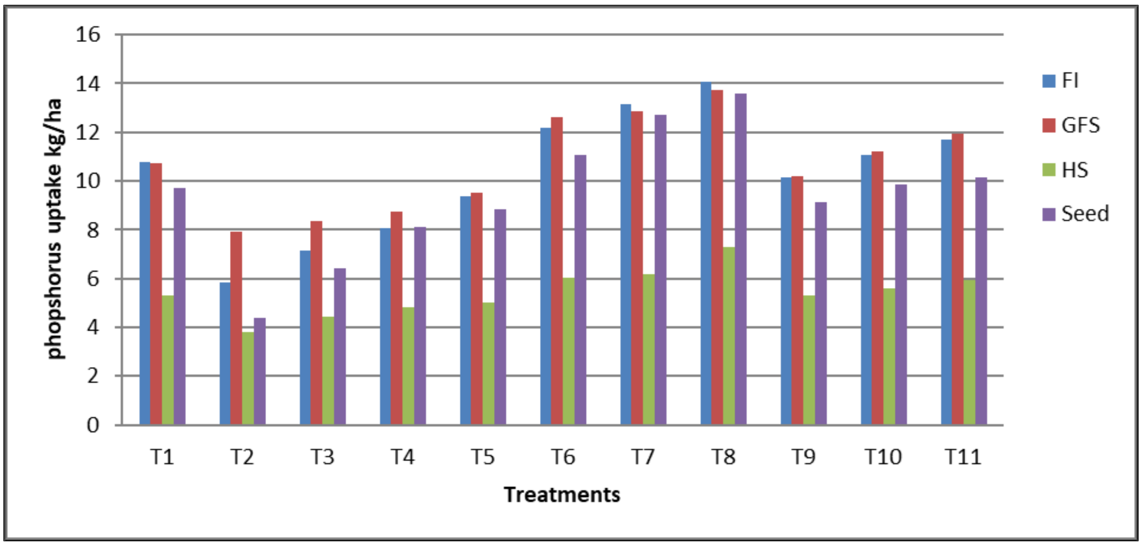

Fig 3: Phosphorus uptake (kg ha-1) of Sunflower at different growth stages as influenced by doses and methods of PSB application, and levels of phosphorus

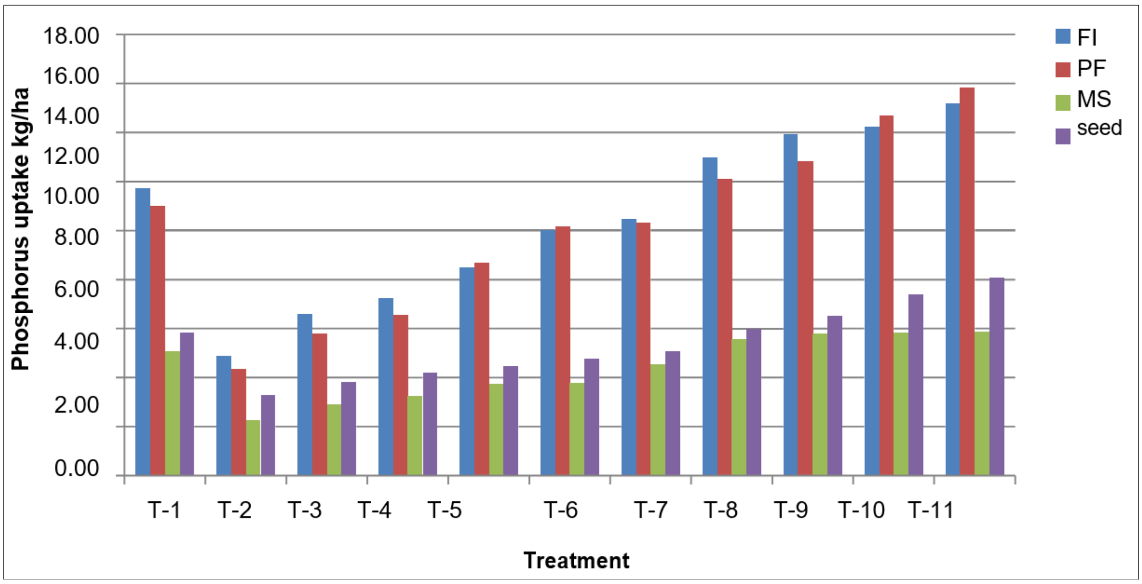

Fig 4: phosphorus uptake (kg ha-1) of chickpea with different growth stages as influenced by doses and methods of PSB application and levels of phosphorus

Conclusion

Single super phosphate as a source of fertilizer in combination with the PSB has a significant effect on the Phosphorus content in shoot and seed and also has a significant effect on the p uptake. Due to combined application of the PSB with phosphorus fertilizer there was a significant results with 75% of phosphorus rather than 100% P in sunflower and in chickpea highest uptake and p content was seen with 50% of the P levels. Hence, saving of the 25% of the phosphorus fertilizer in sunflower and 50% of the fertilizer in chickpea was observed.

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