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Effect of Phosphate and Potash Solubilizing Bacteria on Growth and Yield of Popcorn (*Zea mays* L. Var. *Everta*)

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ABSTRACT

A field experiment was carried out during rabi season of 2016-17 to evaluate the effect of different levels of PSB and KSB on growth and yield of maize. The experimental results revealed that application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application promoted growth parameters viz., plant height, dry matter per plant, functional leaves per plant, number of internodes per plant and yield attributes viz.,cob length, cob girth, number of grain rows per cob, 100 grain weight, grain weight per cob, shelling percentage and ultimately gave higher grain yield (3452 kg/ha) and straw yield (5300 kg/ha) with higher net return (₹ 40018 ha) and B:C ratio (2.11) over the control. Application of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application enhanced growth parameters viz., plant height, dry matter per plant, functional leaves per plant, number of internodes per plant and yield attributes viz.,cob length, cob girth, number of grain rows per cob, 100 grain weight, grain weight per cob, shelling percentage and resultantly gave higher grain and straw yield of 3476 and 5295 kg/ha, respectively along with higher net return (₹ 40695/ha) and B:C ratio (2.14) over the control.It could be concluded that seed inoculation and soil application of PSB and KSB enhanced grain yield with higher net return and saving of 25% fertilizer dose of phosphorus and potash.

Key words: *Popcorn, (Zea mays L. Var. Everta), Phosphate solubilizing bacteria, Potash solubilizing bacteria.*

INTRODUCTION

Among the cereals, maize (*Zea mays* L.) ranks third in total world production after wheat and rice and it is principal staple food in many countries, particularly in the tropics and subtropics[4]. Maize is considered as the “Queen of Cereals”.

Phosphorus is the second important key element after nitrogen as a mineral nutrient in terms of quantitative plant requirement. Although abundant in soils, in both organic and inorganic forms, its availability is restricted as it occurs mostly insoluble forms. The P content in an average soil is about 0.05% (w/w) but only 0.1% of the total P is available to plant because of poor solubility and its fixation in soil[8].

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An adequate supply of phosphorus during early phases of plant development is important for laying down the primordial of plant reproductive parts. It plays significant role in increasing root ramification and strength thereby imparting vitality and disease resistance capacity to plant. It also helps in seed formation and early maturation of crop like cereals and legumes. Poor availability or deficiency of phosphorus (P) markedly reduces plant size and growth. Phosphorus accounts about 0.2% - 0.8% of the plant dry weight.

To satisfy crop nutritional requirements, P is usually added to soil as chemical P fertilizer, however synthesis of chemical P fertilizer is highly energy intensive processes, and has long term impacts on the environment in terms of eutrophication, soil fertility depletion carbon. More over plants can use only a small amount of this P since 75–90 % of added P is precipitated by metal cation complexes, and rapidly becomes fixed in soils. Such environmental concerns have led to the search for sustainable way of P nutrition of crops. In this regards phosphate-solubilizing microorganisms (PSM) have been seen as best eco-friendly means for P nutrition.

Next to nitrogen and phosphorus, potassium is the third important plant nutrient. Potassium is essential macronutrient for plant growth and plays significant roles in activation of several metabolic processes including protein synthesis, photosynthesis, enzymes, as well as in resistance to diseases, insects, abiotic stress *etc.*[16]. Potassium though present as abundant element in soil or is applied to fields as natural or synthetic fertilizers, only one to two percent of this is available to plants, the rest being bound with other minerals and therefore unavailable to plants. The most common soil components of potassium, 90 to 98%, are feldspar and mica[11]. Soil microorganisms influence the availability of soil minerals, playing a central role in ion cycling and soil fertility[3]. Very little of this potassium source is available for plant use. Some bacteria were found to solubilize potassium, silicon and aluminum from insoluble minerals[1]. Their uses as bio-fertilizers for agriculture improvement and environmental protection have been a focus of recent research.

At Coimbatore (Tamil Nadu) *Frateuria aurantia* belonging to the family Pseudomonaceae obtained from the agricultural soils was found to solubilize K considerably and promoted the crop yield[15]. This solubilization effect is generally due to the production of certain organic acids and enzymes by KSB.

MATERIAL AND METHODS

The field experiment was conducted during *rabi* season of 2016-17 at Junagadh Agricultural University, Junagadh, Gujarat. Soil of the experimental plot was clayey in texture and slightly alkaline in reaction (pH 7.9 and EC 0.33 dS/m). The soil was medium in available nitrogen (254-269 kg/ha), available phosphorus (28.4-30.7 kg/ha) and available potash (183-185 kg/ha) from 0-15 and 15-30 cm depth. The soil was free from any kind of salinity or sodicity hazards. The popcorn variety 'Amber'was sown at 60 cm row spacing and 20 cm spacing maintain between two plants within row. which is tolerant to leaf blight and excellent popping quality was used for this study.

The experiment comprising of 16 treatment combinations with four levels each of PSB and KSB was laid out in Factorial Randomized Block Design with three replications. Maize variety 'Amber' was sown at 60 cm row spacing and 20 cm spacing maintain between two plants within row. 120 kg N/ha in two equal splits at sowing and 30 DAS was applied uniformly to all the plots. Entire dose of phosphorus and potash as per treatments was applied at sowing.

The experiment comprise of 16 treatment combinations was laid out in Factorial Randomized Block Design (FRBD) with three replications. Treatment include four level of phosphate treatment viz., Control(P_0), 60 kg P_2O_5/ha (P_1), 45 kg P_2O_5/ha + PSB seed inoculation (P_2), 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) and four level of phosphate treatment *viz.*, Control (K_0), 60 kg K_2O/ha (K_1), 45 kg K_2O/ha + KSB seed inoculation (K_2), 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3). Application of 120 kg N/ha in two equal splits at sowing and 30 DAS was applied uniformly to all the plots. Entire dose of phosphorus and potash as per treatments was applied at sowing.

Liquid formulation of PSB (*Bacillus subtilis*) obtained from Department of Plant Pathology, College of Agriculture, Junagadh Agricultural University, Junagadh, and KSB (*Frateuria aurantia*), obtained from Department of Plant Pathology, N. M. College of Agriculture, Navsari Agricutural University, Navsari, were used for seed treatment as well as for soil application. For seed treatment, seeds were spreaded and PSB/KSB culture (10^8viable cells/g) @ 30 mL/kg of seed was sprinkled on the seeds and then dried in shade. For soil application, PSB/KSB culture (10^8 viable cells/g) @ 3000 mL/ha was mixed with FYM and than applied in furrows just after sowing before irrigation. The effectiveness of either seed and/or soil inoculation with fertilizer was assessed in the plant growth parameters like plant height, dry matter per plant, functional leaves per plant, number of internodes per plant and yield attributes *viz.*,cob length, cob girth, number of grain rows per cob, 100 grain weight, grain weight per cob, shelling percentage, grain and fodder yield. The economics of different treatment combinations was worked out in terms of net returns/ha and B: C (benefit cost) ratio.

RESULTS AND DISCUSSION

EFFECT OF PSB

Effect of PSB on growth parameters

Growth parameters (Table 1) *viz.*, plant height at 60 DAS and harvest, dry matter per plant at 30 DAS, 60 DAS and harvest, functional leaves per plant at 60 DAS and harvest, number of internodes per plant, were significantly influenced by different levels of PSB.

Fertilizing the crop with 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) significantly increased the growth parameters such as plant height at 60 DAS and harvest; dry matter per plant at 30 DAS, 60 DAS and harvest, functional leaves per plant at 60 DAS and harvest and number of internodes per plant at harvest (Table 1), being statistically equivalent with 45 kg P_2O_5/ha + PSB seed inoculation (P_2) except dry matter per plant at 30 DAS, functional leaves per plant at 60 DAS and number of internodes per plant at harvest. While the lowest value of growth parameters were observed under the control treatment (P_0). PSB inoculation augments plant growth attributed to the production of higher quantities of growth promoting substances and complementary effect of enhanced phosphate availability[19] Tipodiya and Yubby[18] observed that the inoculation of PSB along with 5 t/ha FYM the values of all growth parameters (plant height, green leaves, leaf area, LAI and dry matter production per plant) recorded higher and remained lower under control. Hussain *et al.*[7] evaluated that the inoculation with PSB significantly increased shoot length, root length, shoot fresh and dry weight, root fresh and dry weights up to 39.7, 58.9, 99, 69.4, 97.7 and 87%, respectively over uninoculated control.; in a pot trial activity and mineralization potential of organic P in soil; Hashem *et al.*[6] evaluate that evaluate the PSB strain capable of solubilization of both organic and inorganic phosphorus, also mineralization potential of organic P in soil and enhanced growth and yield of maize at different FYM levels i.e. 0, 8 and 16 t/ha.

Effect on yield attributes and yield

The yield attributes such as cob length, cob girth, number of grain rows per cob, grain weight per cob, 100 grain weight and shelling percentage (Table 2) differed significantly due to application of PSB.

Application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) and 45 kg P_2O_5/ha + PSB seed inoculation (P_2) significantly increased of cob length, cob girth, number of grain rows per cob and Grain weight per cob (g) over the control (P_1)(Table 2). However, 100 grain weight and shelling percentage significantly highest with application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) (Table 2). The control (P_0) recorded significantly the lowest value in all of the cases. Enhanced yield attribute might be due to PSB produces phytohormones and growth promoting substances, resulted in vigorous growth and consequently produce higher biomass per plant and also providing better nutrition throughout the growth period more availability of photosynthesis, metabolites and nutrient to develop reproductive structures seems to have resulted in increased productive part and more availability of phosphorus at flowering and grain filling stages which help in formation of more number of grains/cob. PSB stimulate absorption of nutrient particularly nitrogen, phosphorus and potassium by maize grain, which provide better nourishment, filling and development of grain and consequently the highest test weight, Wahid *et al.*[20]. Result is close conformity with Jat *et al.*[9] revealed that application of 120 kg N/ha + bio-fertilizers (*Rhizobium* + *Azospirillium* + PSB) significantly produced maximum number of cobs per plant, number of grains per cob, cob length, cob girth, 1000-grains weight, grain and stover yield of maize.

Maize crop fertilized with 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) produced significantly the highest grain yield (3452 kg/ha) and fodder yield (5301 kg/ha), which was 22.45 and 21.01% higher, but it was remained comparable with application of 45 kg P_2O_5/ha + PSB seed inoculation (P_2) produced high grain yield (3276 kg/ha) and fodder yield (5128 kg/ha), which was 16.18 and 17.08% over the control (P_0) (Table 3). The beneficial effect of phosphorus and PSB on yield might be due to the continuous and additional supply of plant nutrients as well as improvement in physico-chemical properties of soil. Similar improvement in yield of maize due to integrated use of phosphorus and PSB due to increase bacterial colony and made more available nutrient during crop development stage and concequently increase yield an also net return and B:C ratio has been also been reported by Kaur and Reddy[10]. Application of a mixture of PSB and PSF with phosphate fertilizer with dose 50% recommendation gave a better effect on yield of maize reported by Fitriatin *et al.*[5].

Effect of PSB on quality parameter and economics of maize

Quality parameter *viz.*, leaf chlorophyll content at 30 DAS and 60 DAS and protein yield was significantly highest with application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) and 45 kg P_2O_5/ha + PSB seed inoculation (P_2) as compared to the control (P_0) (Table 3). However, application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) gave maximum net return (₹ 40018/ha) and B:C ratio (2.11)(Table 3), followed by application of 45 kg P_2O_5/ha + PSB seed inoculation (P_2) with net return of ₹ 36531/ha and B:C ratio of 2.02might be due to higher grain yield and straw yield recorded with these PSB levels (P_3 and P_2) along with comparatively less cost than additional income. Result conformed by Meena *et al*.[12].

EFFECT OF KSB

Effect of KSB on growth parameters

Application of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3) and 45 kg K_2O/ha + KSB seed inoculation (K_2) significantly increased growth parameters like plant height at 60 DAS and harvest; dry matter per plant at 30 DAS, 60 DAS and harvest; CGR during 60 DAS-harvest; functional leaves per plant at 60 DAS and harvest and number of internodes per plant at harvest over the control (K_0) (Table 1). KSB (Frateuriaaurantia) are also known to produce amino acids, vitamins and growth promoting substances like indole-3-acetic acid (IAA) and gibberellic acid (GA_3) which help in better growth of the plants[14]. Archna *et al.*[2] in maize reported that KSB is able to solubilize inorganic source of K like muriate of potash and sulphate by means of production of organic acids in order to improve yield.

Effect of KSB on yield attribute, yield and quality of maize

Yield attributes (Table 2) *viz.*, Cob length; cob girth; number of grain rows per cob; grain weight per cob; 100 grain weight; shelling percentage and quality parameter (Table 3) *viz.*, leaf chlorophyll content at 30 DAS and 60 DAS and protein yield were significantly enhanced with application of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3) and 45 kg K_2O/ha + KSB seed inoculation (K_2) over the control (K_0). Fertilization of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3) and 45 kg K_2O/ha + KSB seed inoculation (K_2) significantly increased grain yield by 22.43 and 17.12 % and fodder yield by 21.00 and 17.04 % high over the control (K_0), respectively (Table 3), might be due to chlorophyll is a major green pigment found in green leaves and is undoubtedly determining the photosynthetic efficiency and productivity of plants. Notably K also played an important role in the synthesis of chlorophyll by taking part in various enzyme activities. Since K is found to influence the total chlorophyll and carotenoid contents of the leaves it may also directly and/or indirectly improve crop yield through increased photosynthesis. Similar observations were also recorded by Panwar and Singh[13].

Effect of KSB on economics of maize

Application of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3) earned maximum net return (**₹** 40695/ha) and B: C ratio (2.14), followed by 45 kg K_2O/ha + KSB seed inoculation (K_2) by giving net return of **₹** 37770/ha and B: C ratio of 2.06 (Table 3). This can be attributed to higher grain yield and straw yield recorded with comparatively less cost than additional income under these treatments. These results are in close conformity with the finding of Savliya *et al*.[17].

Table 1: Effect of different treatments on plant growth parameters

Treatment	Plant height (cm) At		Dry matter per plant (g) at			Functional leaves per plant (g) at		Number of internodes per plant
	60 DAS	Harvest	30 DAS	60 DAS	Harvest	60DAS	Harvest	Harvest
P_0	93.00	162.38	23.04	59.83	136.54	6.82	9.07	11.80
P_1	101.67	168.22	25.00	69.24	139.48	7.27	9.50	11.65
P_2	109.28	171.89	27.16	77.22	167.45	8.91	10.21	12.72
P_3	118.75	181.32	30.13	81.68	171.53	9.97	10.69	13.69
S.Em.±	2.45	4.58	0.58	1.73	4.35	0.23	0.23	0.26
C.D. at 5%	7.06	13.22	1.67	5.00	12.56	0.67	0.67	0.75
K_0	96.78	160.82	22.63	64.66	134.47	7.21	9.37	11.87
K_1	102.43	168.24	25.16	70.27	146.12	7.60	9.55	12.19
K_2	109.17	175.05	27.98	74.49	161.24	8.24	10.00	12.59
K_3	114.31	179.69	29.57	78.55	173.18	9.93	10.55	13.20
S.Em.±	2.45	4.58	0.58	1.73	4.35	0.23	0.23	0.26
C.D. at 5%	7.06	13.22	1.67	5.00	12.56	0.67	0.67	0.75
PxK								
S.Em.±	4.89	9.15	1.16	3.46	8.69	0.46	0.46	0.52
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	8.02	9.28	7.61	8.34	9.79	9.76	8.13	7.25

Table 2: Effect of different treatments on yield attributing parameters of maize

Treatment	Cob length (cm)	Cob girth (cm)	Number of grain rows per cob	Grain weight per cob (g)	100 grain weight (g)	Shelling percentage
P_0	12.00	8.81	11.77	65.07	17.12	68.74
P_1	13.68	8.97	11.99	67.34	18.18	69.82
P_2	15.63	9.62	12.80	75.09	19.58	71.36
P_3	16.13	10.02	13.46	79.40	22.58	81.22
S.Em.±	0.48	0.25	0.27	1.81	0.91	1.09
C.D. at 5%	1.40	0.80	0.79	5.21	2.62	3.16
K_0	12.91	8.49	11.66	64.61	17.28	69.32
K_1	13.52	9.16	12.26	68.96	18.40	71.38
K_2	14.93	9.73	12.93	75.17	20.68	73.79
K_3	16.06	10.05	13.18	78.17	21.09	76.66
S.Em.±	0.48	0.21	0.27	1.81	0.91	1.09
C.D. at 5%	1.40	0.8	0.79	5.21	2.62	3.16
PxK						
S.Em.±	0.97	0.61	0.55	3.61	1.81	2.19
C.D. at 5%	NS	NS	NS	NS	NS	NS
C.V.%	11.67	9.13	7.56	8.72	16.20	5.21

Table 3: Effect of different treatments on quality parameters, yield and economics of maize

Treatment	Leaf chlorophyll content (SPAD value) at		Grain protein yield (kg/ha)	Grain yield (kg/ha)	Fodder yield (kg/ha)	Net return (₹/ha)	B:C ratio
	30 DAS	60 DAS					
P_0	33.28	47.34	295.87	2819	4380	28931	1.87
P_1	34.37	50.68	345.66	3109	4840	32366	1.90
P_2	35.39	52.86	359.07	3276	5128	36531	2.02
P_3	37.03	54.91	404.88	3452	5301	40018	2.11
S.Em.±	0.64	1.27	16.31	98.35	125.32	-	-
C.D. at 5%	1.84	3.66	47.10	284.04	361.95	-	-
K_0	32.66	47.57	311.72	2839	4376	28628	1.84
K_1	34.75	48.65	322.84	3015	4858	30749	1.86
K_2	35.87	52.67	365.52	3325	5121	37770	2.06
K_3	36.78	56.91	405.40	3476	5295	40695	2.14
S.Em.±	0.64	1.27	16.31	98.35	125.32	-	-
C.D. at 5%	1.84	3.66	47.10	284.04	361.95	-	-
PxK							
S.Em.±	1.28	2.54	32.61	196.69	250.64	-	-
C.D. at 5%	NS	NS	NS	NS	NS	-	-
C.V.%	6.31	8.54	16.00	10.77	8.84	-	-

CONCLUSION

On the basis of one year field experimentation, it seems quite logical to conclude that higher production and net returns from popcorn (var. Amber) can be secured by application of 45 kg P_2O_5/ha + PSB seed inoculation (30 mL *Bacillus subtilis*/kg seed) + PSB soil application (3 L *Bacillus subtilis*/ha) and 45 kg K_2O/ha + KSB seed inoculation (30 mL *Frateuria aurantia*/kg seed) + KSB soil application (3 L *Frateuria aurantia*/ha) at sowing along with 120 kg N/ha (50% as basal + 50% as top dressing at 30 DAS) on medium black calcareous clayey soil having medium status of available N, P and K under South Saurashtra Agro-climatic Zone. It could be concluded that seed inoculation and soil application of PSB and KSB enhanced grain yield with higher net return and saving of 25% fertilizer dose of phosphorus and potash.

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