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Effect of phosphorus and potassium solubilizing bacteria on growth and yield of popcorn (*Zea mays* L. Var. *Everta*)

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Abstract
The area experiment was laid out during *Zaid* season of 2021 at Crop Research Farm, Department of Agronomy, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P). The experiment was conducted in randomized block design with ten treatments and each replicated three times. Results obtained that notably maximum plant height (173.05 cm), number of leaves (6/plant), leaf area index (3.81), dry weight (140.08 g/plant), crop growth rate (229.95 g/m^2/day), cobs (1.67/plant), cob girth (10.97 cm), rows/cob (12.13), kernels/row (34.07), cob weight with husk (55.47 g), seed index (17.32 g), kernel yield (3.56 t/ha) and stover yield (5.62 t/ha) have been recorded with application of 45 kg P/ha + PSB (seed + soil) along with 45 kg K/ha + KSB (seed + soil). However, cob length (18.13 cm), cob weight without husk (43.89 g) and harvest index (39.24%) were obtained significantly highest values in 45 kg P/ha + PSB (seed + soil) along with 45 kg K/ha + KSB (soil). Maximum gross returns (Rs. 79,698.60/ha), net returns (Rs. 51,589.65/ha) and benefit: cost ratio (1.84) were obtained highest in the treatment combination of 45 kg Phosphorus and potassium/ha along with PSB and KSB (seed + soil) compared to control plot.

Keywords: Kernel yield, phosphorus solubilizing bacteria, potassium solubilizing bacteria, stover yield and economics

Introduction
Maize is classified into seven principle groups on the basis of endosperm and floral bract or glume character *viz*., dent corn, popcorn, flint corn, soft corn, sweet corn and waxy corn. Corn is grown in India on an area of roughly 9.18 million hectares, with a yield of 27.23 million tonnes and an average productivity of 2965 kg/ha, making it the world's fifth largest producer, accounting for three percent of global production. Madhya Pradesh tops first with the contribution of 14.87 per cent (1.37 million tonnes) to the total maize grown area in India. Karnataka produces corn of about 3.73 million tonnes with of 13.69% among the states and highest productivity was noticed in Tamil Nadu of about 6551 kg/ha. While, Uttar Pradesh contributes an area of about 0.73 million hectares with 7.98% to all over India which has the production of about 1.53 million tonnes (5.63% to all-India) and productivity is 2090 kg/ha, respectively (Agricultural Statistics at a Glance, 2019) [2].

Popcorn is often known as popping corn because of the characteristics of the kernels, and it is one of the most popular snack item in many regions of the world. It has a unique ability to pop. Popcorn has a shorter, more slender stalk and thinner cobs than field maize and matures earlier. It contains edible protein with 15 grammes of dietary fibre, 0.2 milligrammes of thiamine, 0.3 milligrammes of riboflavin, 4 grammes of protein and 2.7 milligrammes of iron per 100 milligrammes. It has enormous potential because it increases the farmer's compensation.

Phosphorus is typically brought to soil as chemical P-fertilizer, but synthesis of chemical P-fertilizer is high-energy intensive process with long term environmental consequences such as eutrophication and soil fertility degradation. Furthermore, because 75-90 percent of additional P is precipitated by metal cation complexes and quickly becomes fixed in soils, plants can only use a tiny quantity of it. As a result of these environmental problems, researchers are looking for a long-term solution for crop P nutrition. The phosphate solubilising bacteria (PSB) are rhizobacteria that use acidification, chelation, exchange processes and organic acids to transform insoluble phosphates into soluble forms. (Rodriguez and Fraga, 1999) [19].

Potassium is a vital macronutrient for plant growth and plays a key role in activation of numerous metabolic processes such as protein synthesis, photosynthesis and enzymes, as well as disease, pest and abiotic stress tolerance. Soil microbes play a key role in iron cycling and soil fertility by influencing the availability of soil minerals. Plants can use only a small portion of this potassium because most of the potassium gets fixed in soil as crystalline structure of feldspars, clay minerals and micas which are in insoluble form. Potassium solubilizing bacteria (KSB) were discovered to dissolve potassium, silicon and aluminium from insoluble potassium-bearing minerals such as micas, illite and orthoclases by means of excreting organic acids that either directly dissolved rock K or chelated silicon ions to convert potassium into the solution (Bin *et al*., 2010) [8].

Materials and Methods

The field experiment took place at the crop research farm, Department of Agronomy, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, during the *Zaid* season of 2021(U.P). The crop research farm is located at 25.57^0 North latitude, 87.19^0 East longitude and at an altitude of 98 metres above mean sea level. The experiment laid was out in Randomized Block Design consisting of ten treatments which are T_1: Control, T_2: 45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed), T_3: 45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (soil), T_4: 45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed + soil), T_5: 45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed), T_6: 45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (soil), T_7: 45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed + soil), T_8: 45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed), T_9: 45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (soil) and T_{10}: 45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed + soil) replicated three times to see how phosphorus and potassium solubilizing bacteria affect popcorn development and yield. The soil in the trail plot was sandy loam in texture, pH 7.1, low in organic carbon (0.36percent), available N (171.48 kg/ha), medium in available P and K (15.2 kg/ha and 232.5 kg/ha respectively). The recommended doses of 120 killogrammes of Nitrogen, 60 killogrammes of Phosphorus, 40 killogrammes of potassium per hectare were administrated according to the instructions. Whereas, seeds were inoculated with Phosphorus and Potassium solubilizing bacteria by taking 25g of PSB and KSB which is mixed with 1kg of seeds with the help of jaggery solution and it is shade dried for 30 minutes before sowing. PSB and KSB are also applied through soil by taking 25-30kg of PSB and KSB mixed with 10t of FYM/ha and it is broadcasted in the field. Between the period of germination to harvest several plant growth parameters were recorded at equal intervals and after harvest several yield parameters were recorded. Plant height (cm), number of leaves per plant, leaf area index and dry weight (g/plant) were recorded in growth parameters, while cobs/plant, cob length (cm), cob girth (cm), rows/cob, kernels/cob, cob weight (with husk and without husk) seed index (g), kernel yield (t/ha), stover yield (t/ha) and harvest index (percent) were recorded in yield parameters and statistically evaluated using analysis of variance (ANOVA) as applied to Randomized Block Design at 5% level of significance (Gomez, K. A. and Gomez, A. A. 1984).

Results and Discussion

Growth attributes

Table 1 shows the statistical information on growth parameters.

Plant height (cm)

Data indicated that significantly highest plant height (173.05 cm) of popcorn was recorded in 45 kg P and K/ha with PSB and KSB (seed + soil) whereas T_9 and T_8 (160.56 and 165.76 cm) was recorded statistically on par with highest. Significant differences in plant height could be attributed to the plant's inability to get the nutrients they need at critical growth stages. Inoculation of PSB through seed and soil along with Phosphorus helps the plants to get more P intake because PSB can convert the non- available organic phosphate to soluble form, thus increasing the availability of phosphorus by secreating organic acids in rhizosphere of soil. Due to increase in phosphorus availability and other nutrients both shoot and root growth is increased which helps in increase of plant height. As potassium fertilizer was applied along with KSB which were able to dissolve K bearing minerals by exerting organic acids and making K available to plants, thus helping the plants to show more plant growth.

Number of leaves and Leaf area index

The data shows no significant difference in number of leaves and Leaf area index. However, more number of leaves (6.00/plant) and greatest Leaf area index (3.81) were obtained in T_{10}. Whereas, minimum number of leaves (4.80/plant) and lower Leaf area index (2.99) were noticed in control plot, respectively. The maize plant is less adaptable than other members of the grass family. Even at low plant densities, modern maize cultivars do not tiller much, and produce only one cob per plant. As a result, maize varieties lack the flexibility of most crop species, which can branch at low crop densities to increase leaf area and reproductive units.

Dry weight

The data in Table 1 pertaining that there was significantly highest dry weight (140.08 g/plant) by application of 45kg phosphorus and potassium/ha with PSB and KSB (seed + soil) and following treatments recorded on par values 45 kg P and K/ha with PSB (seed + soil) and KSB (soil) and Treatment-8 (132.65 and 131.67 g/plant). The increase in biomass might be due to PSB and KSB applications along with Phosphorus and Potassium fertilizers which helped to increase their intake and also helped to produce some natural acids with inside the rhizosphere which helped to promote cell wall permeability and photosynthetic activity ultimately increased plant growth and dry weight.

Plant development is boosted by PSB inoculation due to increased synthesis of growth promoting chemicals and the complimentary effect of increased phosphorus availability (Tetarwal *et al.* 2011) [25] in maize. The findings are consistent with those of Jordan and Caldwell (2012) [14] in wheat and maize, Abbas *et al.* (2013) [1] in maize, Hussain *et al.* (2013a) [12] in maize, Hussain *et al.* (2013b) [12] in maize, Tipodiya and Yubby (2013) in maize, Amanullah and Shah (2015) [3] in maize, Manzoor *et al.* (2016) [17] in maize, Viruel *et al.* (2014)[29] in maize and Hashem *et al.* (2017) [17] in maize.

Archna *et al.* (2008)[4] in maize reported that in order to boost yield, KSB can solubilize inorganic source of potassium like muriate of potash and sulphate by producing organic acids. According to Bagyalakshmi *et al.* (2012)[6] using an indigenous KSB formulation with various doses of potash fertilizers containing N and P increased green leaf production and productivity in tea. The boost in output could be related to the production of organic acids such as citric, ferulic, coumaric,

syringic and malic acid by KSB, which helps to solubilize nutrients in the soil.

Organic acids have been shown to aid mineral weathering by directly dissolving K from rocks or by creating metal organic complexes by with silicon ions to bring the K into the solution (Sheng XF and Huang WY (2002) [24].

Yield and yield attributes

The statistical data representing yield and yield attributes is presented in Table 2.

Number of cobs per plant and cob length were recorded no significant difference between the treatments. However, the highest number of cobs per plant (1.67) and cob length (18.13 cm) were recorded in $T_{10.}$ Cob girth (10.97 cm) was significantly highest with application of 45 kg P and K with PSB and KSB (seed + soil) whereas T_9 and T_8 (10.71 cm, 10.63 cm) were recorded statistically on par with highest. Significantly highest number of rows per cob (12.13) was noticed in T_{10} whereas application of 45 kg P and K/ha with PSB (seed + soil) and KSB (soil) and T_8 (12.00 and 11.60) were recorded statistically on par with highest. Kernels per row (34.07) was significantly highest in 45 kg Phosphorus and potassium/ha along with PSB and KSB (seed + soil) where as T_9 and T_8 (33.13 and 32.47) were recorded statistically on par with highest.

Cob weight per plant with husk recorded a significant difference among treatment combinations. However, cob weight with husk (55.47 g) recorded significantly highest by application of 45 kg phosphorus and potassium/ha with PSB and KSB (seed + soil) and on par values were observed in T_9 and 45 kg Phosphorus and potassium/ha with PSB (seed + soil) and KSB (seed) (52.35 and 51.98 g, respectively). Significantly highest cob weight without husk (43.89 g) was recorded in T_9 whereas application T_{10} and 45 kg Phosphorus and potassium/ha + PSB and KSB (soil) (43.34 and 39.83 g) were recorded statistically on par with highest. Significantly higher seed index (17.32 g) was noticed in 45 kg Phosphorus and potassium/ha with PSB and KSB (seed + soil) which was on par with T_9(16.35 g), respectively kernel yield (3.56 t/ha) recorded significantly highest in Treatment-10 and on par values were observed in Treatment-9 and Treatment-8 (3.43 and 3.22 t/ha), respectively. Stover yield (29.47t/ha) was significantly highest in T_{10} whereas application of 45 kg Phosphorus and potassium/ha with PSB (seed + soil) and KSB (soil) and T_4 were recorded statistically on par with highest (5.28 and 5.23t/ha). The data shows that no significant difference was recorded in harvest index between the treatments. However, highest harvest index (39.24%) was noticed in T_9 and least was occurred in control plot (37.22%), respectively.

Treatment-10 demonstrated a considerable improvement in overall crop growth as measured by plant height and functional leaves per plant as a result of increased photosynthetic efficiency, as mentioned in the preceding section. More photosynthesis, metabolites, and nutrients available to create reproductive structures appear to have led in more productive plants such as cob girth, rows per cob, kernels per row, weight of cob with husk, seed index, kernel yield and stover yield with this treatment. The current findings are similar to those reported by Singh and Rai (2002) [21] using PSB application in wheat, Chaturvedi (2006) [10] in wheat, Fitriatin *et al*. (2014) [12], Jat *et al*. (2014) [13] in maize, Chopra *et al.* (2016) [9] in wheat.

The increase in grain and fodder yields with these treatments might be due to PSB which produces phytohormones and growth promoting substances, results in effective growth and therefore produce better biomass consistent with plants and additionally supply higher nutrients throughout the growth duration and availability of phosphorus at flowering and grain filling stages which aids in formation of grater range of grains/cob. PSB increases nutrient absorption by maize grain, notably nitrogen, phosphorus and potassium, resulting in improved grain feeding, fullness, and development, as well as the greatest test weight. The outcome is consistent with Wahid *et al.* (2013) [30]. Higher straw output was due to profound increase in growth in terms of plant height, dry matter per plant, functional leaves per plant under PSB treatment.

Chlorophyll is a significant green pigment present in green leaves that determines how efficient and productive plants are at photosynthetically. K, in particular, played a key role in the synthesis of chlorophyll by participating in a variety of enzyme activities. Because K has proven to alter the total chlorophyll and carotenoid content of leaves, it may improve crop productivity directly or indirectly by increasing photosynthesis. Observations similar to this were also made by Mikhailouskaya and Tcherhysh (2005) [18] in wheat, Balasubramaniam and Subramanian (2006) [6] in rice, Mikhailouskaya *et al.* (2005) [20] in wheat, Basak and Biswas (2010) [6] in forage crop.

Economics

The Data in table 3 showed that T_{10} recorded highest gross returns (79,698.60 INR/ha) net returns (51,589.65 INR/ha) and benefit: cost ratio (1.84). This is due to the increased kernel and stover yield achieved with these PSB and KSB levels along with comparatively less cost than additional income.

The present experimental results suggest that reduction in one forth quantity of recommended dose of phosphatic fertilizer (15 kg/ha) could be made by the application of PSB and KSB without any decrease in yield. The beneficial effect of these solubilizing bacteria on yield is related to the constant and increased supply of plant nutrients, as well as improvements in soil physico-chemical parameters. Similar increases in maize output due to integrated use of PSB and KSB, which increased due bacterial colony and made more nutrients available during crop growth stage, resulting in increased yield, net return and B:C ratio. Other workers also confirmed it *viz*. Bharti *et al*. (2010) [7] in wheat, Kumar and Singh (2010) [15] in wheat, Sepat *et al*. (2010) [21] in wheat, Shirpurkar *et al.* (2010) [23] in ground nut-wheat, Lone *et al.* (2011) [16] in wheat, Verma *et al.* (2015) [26] in wheat and Savliya *et al*. (2014) in wheat.

Table 1: Impact of phosphorus and potassium solubilizing bacteria on the parameters of growth in pop corn

Treatments	AT HARVEST			
	Plant height (cm)	No. of leaves	Leaf area index	Dry weight (g/plant)
Control	137.43	4.80	2.99	107.87
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed)	137.93	4.93	3.04	119.24
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (soil)	139.71	5.00	3.23	120.00
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed + soil)	150.79	5.53	3.48	123.03
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed)	141.13	5.20	3.26	121.62
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (soil)	146.23	5.07	3.47	122.01
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed + soil)	154.15	5.40	3.52	124.56
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed)	160.56	5.33	3.60	131.67
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (soil)	165.76	5.60	3.76	132.65
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed + soil)	173.05	6.00	3.81	140.08
S.Em+	5.58	7.71	0.22	5.12
CD (P=0.05)	16.59	-	-	15.20

Table 2: Effect of phosphorus and potassium solubilizing bacteria on yield attributes and yield of popcorn

Treatments	Cobs/ plant	Cob length (cm)	Cob girth (cm)	Rows /cob	Kernels / row	Cob weight (g)		Seed index (g)	Kernel yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
						With husk	Without husk				
Control	1.20	14.99	8.35	10.93	28.87	38.69	34.00	13.96	2.80	4.72	37.22
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed)	1.27	14.58	8.49	11.00	29.00	39.32	34.66	14.01	2.93	4.87	37.54
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (soil)	1.33	16.35	8.57	11.20	29.20	42.80	37.14	14.50	2.98	4.92	37.75
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed + soil)	1.40	16.47	9.29	11.33	31.07	45.68	35.61	15.43	3.15	5.23	37.58
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed)	1.47	16.41	8.79	11.27	27.87	43.23	37.17	14.58	3.06	5.14	37.30
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (soil)	1.53	16.45	9.00	11.07	29.53	47.12	39.83	14.89	3.07	4.87	38.62
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed + soil)	1.40	16.75	8.95	11.33	31.53	48.02	35.56	15.93	3.16	4.96	38.88
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed)	1.47	17.09	10.63	11.60	32.47	51.98	37.41	16.05	3.22	5.20	38.30
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (soil)	1.60	18.13	10.71	12.00	33.13	52.35	43.89	16.35	3.43	5.28	39.24
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed + soil)	1.67	17.55	10.97	12.13	34.07	55.47	43.34	17.32	3.56	5.62	38.84
F-Test	NS	NS	S	S	S	S	S	S	S	S	NS
S.Em+	0.11	0.77	0.61	025	0.83	2.47	2.07	0.36	0.12	0.16	1.03
CD (P=0.05)	-	-	1.80	0.73	2.47	7.34	6.15	1.07	0.37	0.47	-

Table 3: Effect of phosphorus and potassium solubilizing bacteria on economics of popcorn

Treatments	Cost of cultivation (INR/ha)	Gross returns (INR/ha)	Net returns (INR/ha)	B:C ratio
Control	26,527.40	63,093.80	36,566.40	1.38
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed)	25,916.45	65,915.00	39,998.55	1.54
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (soil)	27,071.45	66,964.00	39,892.55	1.47
45 kg P/ha + PSB (seed) + 45 kg K/ha + KSB (seed + soil)	27,108.95	70,335.53	43,226.58	1.59
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed)	26,878.95	68,943.40	42,064.45	1.56
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (soil)	28,033.95	68,656.00	40,622.05	1.45
45 kg P/ha + PSB (soil) + 45 kg K/ha + KSB (seed + soil)	28,071.45	70,594.20	42,522.75	1.51
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed)	26,916.45	72,284.00	45,367.55	1.69
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (soil)	28,071.45	76,562.20	48,490.75	1.73
45 kg P/ha + PSB (seed + soil) + 45 kg K/ha + KSB (seed + soil)	28,108.95	79,698.60	51,589.65	1.84

Conclusion

From the above experiment it is concluded that the application of 45 kg Phosphorus and Potassium/ha with PSB and KSB (seed + soil) is highly remunerative practice registering higher productivity and thereby realizing a higher monetary advantage.

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