E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(6): 211-215
Received: 11-06-2024
Accepted: 22-06-2024

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Impact of potassium levels and potassium solubilizing bacteria on yield and economics of maize (*Zea mays* L.) in *kharif* season

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i6Sd.845

Abstract
The field experiment was conducted during *kharif* season of 2021 to 2023 at main maize research station, Anand agricultural university, Godhra (Gujarat). The soil of the experiment plot was sandy loam in texture, nearly neutral in soil reaction (pH 7.5), low in organic carbon (0.40%), medium in available P (58.0 kg/ha) and high in available K (279.4 kg/ha). The treatments consisted of five Levels of K_2O (K_0: 0 kg K_2O ha^{-1} (K_1: 20 kg K_2O ha^{-1}, K_2: 40 kg K_2O ha^{-1}, K_3: 60 kg K_2O ha^{-1} and K_4: 80 kg K_2O ha^{-1}) with and without bio fertilizer (KMB seed treatment and soil application). The experiment was laid out in randomized block design with ten treatments and was replicated thrice. Result defined that test weight of maize was significantly highest with application of 20 kg K_2O ha^{-1}, the grain yield, AV. P_2O_5 and AV. K_2O. were maximum observed when KMB (5 ml kg^{-1} seed at sowing + soil application of KMB@ 1 liter/ha after 30 DAS) was apply, highest content of K in straw of maize was found with Application of 60 kg K_2O/ha+ KMB (potassium mobilizing bacteria) 5 ml/kg seed and @ 1 liter ha^{-1}. Seed treatment (5 ml/kg seed) and soil application (1 lit/ha) gave net realization (Rs. 1,09,309) with higher BCR (4.22).

Keywords: Grain yield, KMB, K content, economics, BCR

Introduction

Potassium (K) is the third most important plant nutrient (Ahmad *et al.* (2016) [1] and the 7th most abundant element in the earth crust (Etesami *et al.*, 2017) [6]. It is considered by plant physiologists to be second to nitrogen in promoting plant growth (Meena *et al.*, 2014) [10]. Potassium (K) plays a key role in plant growth, resilience to stress, metabolism, development, and reproduction. It's involved in photosynthesis, adenosine triphosphate (ATP) production, translocation of sugars, water and nutrient transport, starch synthesis, legume-based nitrogen fixation, enzymes, and protein syntheses (Wolde, 2016) [20]. Despite its abundance, only less than 2 to 3% of soil K is available to plants in free soluble form because the rest remains bound to other soil minerals, constituting an estimated 95% of soil potassium (Etesami *et al.*, 2017) [6]. In the soil, there are four forms of potassium and these include unavailable K (mineral K), available K (soluble K), non-exchangeable K (fixed or trapped K), and exchangeable K (ionic K).

The fixed K is a reserve source of potassium, while the exchangeable K (ionic K) is readily taken up by the plant's root system and substitute for potassium on the exchange sites. Additionally, some are contained in organic matter within the soil microbial population (Kour *et al.*, 2020) [9]. Potassium uptake by plants varies with different plants, and it is most needed at the early growth stage of the plant more than nitrogen and phosphorus (Sattar *et al.*, 2019) [17]. Its uptake is mainly affected by soil moisture, soil temperature, and tillage system (Mouhamad *et al.*, 2016) [11]. Potassium deficiency is not readily manifested physically in plants unlike nitrogen and phosphorus (Wolde, 2016) [20]. This consequently attracted many farmers to the application of only nitrogen and phosphorus fertilizers over potassium (Hamid and Bashir, 2019) [7].

The unpopular use of inorganic K-fertilizers, particularly among the tropical farmers, with potassium-deficient soil alters plant physiology and reduced yields of crops as well as exacerbating crop sensitivity to pests and diseases (Hamid and Bashir, 2019) [7]. Potassium deficiency decreased the production in natural ecosystems (Chen *et al.*, 2020) [5]. However, the application of K fertilization increased yields and improved N and P use efficiency (Niu *et al.*, 2013) [13].

Potassium solubilizing microorganisms solubilize mineral potassium that are unavailable to plant to become accessible and available to plant (Meena *et al.* 2014) [10], PSM mobilizes K from soil mineral making such available to plants (Pandey *et al.* 2020) [14]. Jain *et al.* (2022) [8] explains that potassium solubilizing microorganisms convert the unavailable form of mineral K to forms that are available to plant, indicating that KSMs possess a potential to improve the potassium availability in soils and hence can play an important role in the potassium nutrient management the condition of K-limited soils and can therefore reduce the use of potassium-based chemical fertilizers. This is because soil microorganisms such as KSMs play a significant role in natural K cycle (Hamid and Bashir, 2019) [7]. Potassium solubilizing microorganisms (KSMs) as biofertilizer Soil potassium replenishment, particularly in smallholder agriculture, remains a challenge as it is achieved mainly by fertilizer (Prajapati *et al.*, 2012) [15]. The discovery and utilization of potassium solubilizing microorganisms like bacteria as bio-fertilizer will regress reliance on agrochemicals, particularly soluble potassium fertilizer (Hamid and Bashir, 2019) [7].

Maize is (*Zea mays* L.) is the third most important cereals next to rice and wheat in the world as well in India, contributing about 20 per cent share of worlds total cereal production. Maize is being consumed both as food and fodder crop and also required by various industries in India. Maize is considered as the “Queen of Cereals” because of its high production potential and wider adoptability. The major maize produce countries in the world are USA, China, South and Central Africa, Argentina, Brazil and Mexico. In India, the important maize growing states are Utter Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Karnataka, Himachal Pradesh and Andhra Pradesh. In India 45 to 48% of Maize produced is consume by human and the rest is use in cattle and poultry feed and by the starch and oil industries. In world, maize occupies an area of 199.9 million ha with the production of 1162.9 million tones and productivity of 5815 kg per ha. In India, maize is grown over an area of 9.56 million ha with the production of 28.76 million tones and productivity is 3006 kg ha^{-1} (Agricultural statistics, 2020) [4]. The area under maize crop in Gujarat is about 0.388 million ha. The production of 0.667 million tones and productivity of 1716.32 kg ha^{-1} (2020 – 21) [1]. Maize is an exhaustive crop and utilizes more nutrients from the soil for growth and development. Solubilization of insoluble minerals by bacteria helps to uptake and utilization of nutrient from the soil. Maize absorbs 70-80% potassium at silking stage and 100% potassium is absorbed three to four weeks after silking and it removes around 50 lb acre^{-1} K_2O from soil when grown for grain (Anonymous, 2020) [4].

Materials and Methods

The present experiment was carried out during *Kharif* 2021 to 2023 at main maize research station, Anand agricultural university, Godhra (Gujarat), which is located at an altitude of 119 m above mean sea level on 22º45’00” N latitude and 77º40’18” E longitude. GAWMH-2 variety used for sowing Maize with 160 kg N and 20 kg P_2O_5 ha^{-1}. The experiment laid out in Randomized Block Design which consisting of ten treatments, five Levels of K_2O (K_0: 0 kg K_2O ha^{-1} (K_1: 20 kg K_2O ha^{-1}, K_2: 40 kg K_2O ha^{-1}, K_3: 60 kg K_2O ha^{-1} and K_4: 80 kg K_2O ha^{-1}) and two levels of Biofertilizer, with KMB (seed treatment KMB 5 ml kg^{-1} seed and @ 1 liter ha^{-1} soil application) and without bio fertilizer were replicated thrice. Nutrient sources were Urea and DAP to fulfill the necessity of Nitrogen and phosphorous. The application of fertilizers was applied as basal at the time of sowing. The seeds were inoculated with respective bio fertilizers as per the treatment combinations. MOP was applied in the treatment plots to fulfill the needs of potassium. In the period from germination to harvest several plant growth parameters were recorded at frequent intervals along with it after harvest several yield parameters were recorded, those parameters are growth parameters, plant height, the yield parameters like cob length (cm), cob width (cm), test weight (g), seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) were recorded and statistically analyzed using analysis of variance (ANOVA) as applicable to Randomized Block Design.

Results and Discussion

Effect on Growth and Yield

Plant height, length and girth of cob at harvest

Plant height, length and girth of cob at harvest did not influenced significantly due to different levels of potassium and KMB. However the maximum length of cob was observed with 80 kg ha^{-1} K_2O with KMB application.

Test weight and No. of cobs

Significantly highest test weight was observed with application of 20 kg ha^{-1} K_2O. However treatment T3:40 kg ha^{-1} K_2O, T4: 60 kg ha^{-1} K_2O and T_5:80 kg ha^{-1} K_2O found to be statistically at par with treatment (T_2: 20 kg ha^{-1} K_2O. Similar result regard to yield attributes was found to be in resonance with Goswami and Maurya, (2020) [18]. No. of cobs ha^{-1} did not influenced significantly due to different levels of potassium and KMB.

Grain and stover yield of maize

It was found significant effect of potassium mobilizing biofertilizer on the grain yield. The seed treatment with KMB (5 ml kg^{-1} seed at sowing + soil application of KMB@ 1 liter ha^{-1} after 30 DAS) gave higher yield 5503 kg ha^{-1} than not treated seed as well as no soil application of KMB gave (5123 kg ha^{-1}), Similar outcomes were reported by Goswami and Maurya, 2020 [18]. While application of potassic fertilizer found non significant effect on grain yield. Stover yield was not affected significantly due to different levels of potassium and KMB. However 20 kg K_2O ha^{-1} gave higher stover yield (10935 kg ha^{-1}) and seed treatment (At sowing) as well as soil application of KMB (After 30 DAS) gave higher stover yield (10698 kg ha^{-1}) than no treatment of KMB.

Effect on N, P, K content of grain and plant

Application of 60 kg K_2O ha^{-1}+ KMB (potassium mobilizing bacteria) 5 ml/kg seed and @ 1 liter/ha soil recorded significantly the highest content of K in straw of maize at harvest. Similar result was supported by Chaudhary *et al.*, (2021) [12]. N, P, K content of grain was fount non significant.

Soil microbial population

The total soil microbial count and KMB Bacterial count was found that total KMB Bacterial count after harvesting increased than initial bacterial count.

Nutrients status after harvesting

The application of KMB with seed treatment and soil application

(5 ml/kg seed @ 1 lit/ha after 30 DAS found significant effect on AV. P_2O_5 and AV. K_2O.

Plants damaged by FAW

Plants damaged by fall army worm was found non significant with the application of potassium and bio fertilizer.

Economics

The highest Gross returns (1,53,909 INR/ha), Maximum net returns (1,18,808 INR/ha) and B:C ratio (4.38) were obtained with the application of K_2O 20 kg ha^{-1} + + KMB 5 ml /kg seed and @ 1 liter/ha soil application which was superior over rest of all treatments. Application of potassium and potassium solubilizing bacteria fetched the maximum gross returns (1,28,100 INR ha^{-1}), net returns (84,406.47 INR ha^{-1}) and B:C ratio (1.93) respectively and these results were in line with (Priyavardhini *et al.* 2021) [19]. (Raghavendra *et al.* 2020) [16] revealed that maximum net returns (112488/ha and 125604/ha), B:C ratio (1.9 and 2.1), output energy, system productivity (10.62 t/ha and 11.37 t/ha) were found 50% RDF + KSB consumed only 0.34 –0.35% higher input energy over no K in maize.

Table 1: Effect of potassium application on Plant height, length and girth of cob at harvest

Treatments	Plant height at harvest (cm)				Length of cob at harvest (cm)				Girth of cob at harvest (cm)				Plant stand at harvest			
	2021	2022	2023	Pooled	2021	2022	2023	Pooled	2021	2022	2023	Pooled	2021	2022	2023	Pooled
K_0 (0)	213	206	206	208	15.85	16.61	17.35	16.60	13.10	12.91	12.83	12.95	134	138	139	137
K_1 (20)	213	206	207	209	16.00	16.38	17.15	16.51	12.48	13.25	13.47	13.07	142	144	137	141
K_2 (40)	208	205	217	210	16.70	16.68	17.11	16.83	12.53	13.22	13.30	13.02	140	141	138	140
K_3 (60)	203	208	215	208	17.10	15.92	17.23	16.75	12.47	13.33	13.22	13.01	133	140	138	137
K_4 (80)	202	203	215	207	17.17	16.58	16.87	16.87	12.40	12.73	13.37	12.83	143	141	139	141
S.Em ±	2.01	2.32	1.50	2.9	0.27	0.43	0.32	0.20	0.19	0.30	0.18	0.13	2.752	3.405	1.152	1.509
CD (P=0.05)	6.11	NS	4.46	NS	0.80	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B_0 (without KMB)	208	206	211	208	16.53	16.63	17.25	16.80	12.60	13.10	13.16	12.95	138	141	138	139
B_1 (With KMB)	208	206	212	208	16.59	16.84	17.03	16.82	12.60	13.13	13.31	13.00	139	141	138	139
S.Em ±	1.3	1.4	0.95	0.73	0.17	0.27	0.20	0.13	0.12	0.19	0.11	0.08	1.741	2.154	0.729	0.954
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.42	2.76	1.73	2.33	4.00	6.43	4.50	5.07	3.70	5.54	3.33	4.31	4.86	5.90	2.04	4.59

Table 2: Effect of potassium application on Test weight and No. of cobs at harvest in *kharif* maize.

Treatments	Test weight (g)				No. of cobs ha^{-1}				Grain yield (kg/ha)				Stover yield (kg/ha)			
	2021	2022	2023	Pooled	2021	2022	2023	Pooled	2021	2022	2023	Pooled	2021	2022	2023	Pooled
K_0 (0)	283	258	306	282	62870	71296	74444	69537	5111	5259	5907	5425	10768	9592	10240	10200
K_1 (20)	305	288	325	306	63611	70000	73426	69012	5213	5296	5612	5374	12777	9324	10703	10935
K_2 (40)	308	287	315	303	67222	69907	74444	70524	4945	5111	6093	5383	12203	9509	10898	10870
K_3 (60)	295	300	312	302	61852	68889	74166	68302	5139	5093	5667	5300	11167	9425	9926	10173
K_4 (80)	302	272	318	297	58703	70926	74907	68179	4649	4723	5880	5084	11296	9037	9500	9945
S.Em ±	9.8	2.9	6.2	3.9	3577	2473	921	1481	340	211	244	156	1101	567	331	427
CD (P=0.05)	NS	8.7	NS	11.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	986	NS
B_0 (without KMB)	300	281	312	297	60851	71000	74185	68679	4896	4867	5607	5123	11418	8925	10111	10151
B_1 (With KMB)	298	281	318	298	64851	69407	74370	69543	5126	5326	6055	5503	11866	9829	10397	10698
S.Em ±	6.2	1.9	3.9	2.5	2262	1564	582	937	215	133	154	99	696	358	209	270
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	397	NS	281	NS	NS	NS	NS
CV%	8.04	2.56	4.78	5.66	13.94	8.63	3.04	9.10	16.67	10.16	10.28	12.51	13.17	14.81	7.92	11.96

Table 3: Effect of potassium application on N, P, K content in grain and stover and soil properties after harvesting and fall armyworm damage in *kharif* maize

Treatments	Content in grain %			Content in stover (%)			soil properties after harvesting					FAW damage (%)		
	N	P	K	N	P	K	Soil pH (1:2.5)	Soil EC dsm	OC%	AV. P_2O_5 kg/ha	Av. K_2O kg/ha	2021	2023	pooled
K_0 (0)	1.26	0.50	0.38	0.99	0.25	0.45	7.20	0.42	0.43	61.77	287.20	**2021**	**2023**	**Pooled**
K_1 (20)	1.35	0.46	0.39	0.99	0.32	0.53	7.19	0.37	0.42	61.98	305.60	3.0	5.0	4.0
K_2 (40)	1.33	0.61	0.46	1.01	0.29	0.45	7.05	0.30	0.47	69.40	310.40	4.0	5.0	4.0
K_3 (60)	1.31	0.52	0.43	1.04	0.27	0.55	7.14	0.34	0.43	63.07	288.40	5.0	4.0	4.0
K_4 (80)	1.43	0.56	0.44	1.0	0.32	0.49	6.98	0.30	0.40	60.62	301.60	3.0	5.0	4.0
S.Em ±	0.039	0.041	0.035	0.43	0.021	0.017	0.076	0.03	0.046	4.38	26.56	4.0	4.0	4.0
CD (P=0.05)	NS	NS	NS	NS	NS	0.051	NS	0.08	NS	NS	NS	0.401	0.587	0.611
B_0 (without KMB)	1.34	0.51	0.41	0.99	0.30	0.46	7.12	0.34	0.41	58.82	256.80	1.193	NS	NS
B_1 (With KMB)	1.33	0.55	0.42	1.01	0.27	0.52	7.09	0.34	0.44	67.91	308.80	3.0	4.0	4.0
S.Em ±	0.025	0.026	0.022	0.027	0.021	0.011	0.048	0.016	0.029	2.77	16.80	4.0	5.0	4.0
CD (P=0.05)	NS	NS	NS	NS	NS	0.032	NS	NS	NS	8.24	49.93	0.254	0.372	0.225
CV%	7.12	16.62	16.36	10.42	17.63	8.53	2.61	16.33	13.10	16.95	8.71	NS	NS	NS
Initial	-	-	-	-	-	-	7.50	0.25	0.40	58.00	279.4	19.00	20.00	19.50

Table 4: Effect of potassium application on soil microbes after harvesting of *kharif* maize

Tr. No.	Total Soil Microbial Count*			KMB Bacterial Count * (CFU/g soil)		
	RI	RII	RIII	RI	RII	RIII
T_1	3.0X10^7	6.1X10^7	2.6X10^7	3.5X10^5	2.9X10^5	1.6X10^5
T_2	1.2X10^8	3.0X10^8	3.2X10^8	2.2X10^6	3.5X10^6	3.6X10^6
T_3	3.2X10^7	3.9X10^7	3.6X10^7	4.2X10^5	3.1X10^6	4.3X10^6
T_4	3.0X10^8	5.3X10^8	9.0X10^8	3.8X10^6	6.3X10^7	5.3X10^7
T_5	3.4X10^7	5.7X10^7	1.2X10^7	3.1X10^5	3.5X10^6	6.3X10^6
T_6	4.7X10^8	5.4X10^9	3.3X10^9	6.7X10^6	5.6X10^7	6.8X10^7
T_7	3.7X10^7	6.2X10^7	3.5X10^7	3.5X10^6	2.5X10^6	6.0X10^6
T_8	4.4X10^8	3.4X10^8	3.7X10^9	6.2X10^6	2.9X10^7	3.6X10^7
T_9	2.8X10^7	3.2X10^7	2.9X10^7	2.5X10^6	5.3X10^6	3.8X10^6
T_{10}	5.0X10^9	2.8X10^9	5.4X10^9	4.8X10^7	6.8X10^7	5.4X10^8
Initial:	9.0 x 10^6 cfu/gm			6.8 x 10^3 cfu/gm		

Table 5: Economics

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Gross Realization (Rs/ha)	Total cost of cultivation (Rs/ha)	Net Realization (Rs/ha) (4-5)	BCR 4÷5	Treatment cost
1	2	3	4	5	6	7	8
T_1 K_0B_0	5722	9796	129912	33461	96451	3.88	0
T_2 K_0B_1	6092	11740	143210	33901	109309	4.22	440
T_3 K_1B_0	4888	12462	129399	34661	94738	3.73	1200
T_4 K_1B_1	6333	13092	153909	35101	118808	4.38	1640
T_5 K_2B_0	5944	11833	142408	35861	106547	3.97	2400
T_6 K_2B_1	6240	12574	150183	36301	113882	4.14	2840
T_7 K_3B_0	5722	11074	135663	37061	98602	3.66	3600
T_8 K_3B_1	5611	11259	134830	37501	97329	3.59	4040
T_9 K_4B_0	5759	11925	140047	38261	101786	3.66	4800
T_{10} K_4B_1	6000	10666	137997	38701	99296	3.57	5240
Maize grain price Rs. 15/kg Maize stover price Rs.4.50/kg Fix cost of cultivation Rs.33461/ha K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha, K_3 = 60 kg K/ha, K_4 = 80 kg K/ha B_0 (Without KMB) B_1 (With KMB)							

Table 6: Economics

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Gross Realization (Rs/ha)	Total cost of cultivation (Rs/ha)	Net Realization (Rs/ha) (4-5)	BCR 4÷5	Treatment cost
1	2	3	4	5	6	7	8
K_0 (0 K_2O Kg/ha)	5425	10200	127275	33461	93814	3.80	0
K_1 (20 Kg K_2O/ha)	5374	10935	129817	34661	95156	3.75	1200
K_2 (40 Kg K_2O/ha)	5383	10870	129660	35861	93799	3.62	2400
K_3 (60 Kg K_2O/ha)	5300	10173	125278	37061	88217	3.38	3600
K_4 (80 Kg K_2O/ha)	5084	9945	121012	38261	82751	3.16	4800
B_0 (Without KMB)	4896	10151	119124	33461	85663	3.56	0
B_1 (With KMB)	5126	10698	125031	33901	91130	3.69	440
Maize grain price Rs. 15/kg Maize stover price Rs.4.50/kg Fix cost of cultivation Rs.35461/ha			K_0 = 0 kg K/ha K_1 = 20 kg K/ha K_2 = 40 kg K/ha K_3 = 60 kg K/ha K_4 = 80 kg K/ha		B_0 (Without KMB) B_1 (With KMB)		

Conclusion

It is to be concluded from the results of grain yield achieved that the seed treatment of KMB @ 5 ml/kg seed along with soil application @ 1 lit/ha after 30 DAS gave significantly higher yield (5503 kg/ha.) with high net return (Rs. 1,09,309/ha.) with higher BCR 4.22.

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