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Influence of Microbial Inoculants and their Consortia on Yield and Nutrient Uptake in Maize Grown on Vertisol

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present field experiment was undertaken at Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during *Kharif* season of 2022. Ten different treatment combinations were used in the experiment which included different microbial inoculants and their consortia ie *Azospirillum* + *Bacillus megaterium* (Consortia -I), *Azospirillum* + *Frateuria aurantia* (Consortia-II), *Azospirillum* + *Thiobacillus thioxidans* (Consortia-III), *Azospirillum* + *Pseudomonas strita* (Consortia- IV), *Azospirillum* + *Bacillus megaterium* + *Frateuria aurantia* (Consortia-V), *Azospirillum* + *Bacillus megaterium* + *Thiobacillus thioxidans* (Consortia- VI), *Azospirillum* + *Bacillus megaterium* + *Pseudomonas strita* (Consortia- VII), and control replicated thrice in RBD (Randomized Block Design). Seed treatment of maize was done with microbial inoculants consortia @ 10 ml kg $^{-1}$ seed before sowing with recommended dose of fertilizers. Among all the treatments, *Azospirillum* + *Bacillus megaterium* + *Thiobacillus thioxidans* (Consortia- VII) noted significantly

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higher grain and stover yield of maize (8156.00 and 9836.66 kg ha $^{-1}$ respectively). Furthermore, total uptake of NPK was found significantly higher (395, 99.99 and 170.65 kg ha $^{-1)}$ with consortia VII. Study concludes that recommended dose of fertilizers with microbial consortia helped in improving yield and nutrient content in plants and grain of maize grown in Vertisol.

Keywords: Microbial consortia; maize; yield; nutrient uptake; vertosol.

1. INTRODUCTION

Maize (*Zea mays* L.) is a highly cross-pollinated crop (95%), it is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions, globally maize is known as “Queen of Cereals” because it has the highest genetic yield potential among the cereals. Nutritionally it contains 60 to 68% starch and 7 to 15% protein; also, it has more riboflavin content then wheat or rice crops and is rich in phosphorus and potash content. Maize protein 'Zein' is deficient in tryptophane and lysine, the two essential amino acids. A maize grain has significant quantities of vitamin A, nicotinic acid, riboflavin and vitamin E. Priyavardhini *et al*. [1]. It is cultivated in nearly 205 million ha with a production of 1210 million tons and productivity of 5878 kg/ha all over the world, having wider diversity of soil, climate, biodiversity and management practices [2]. Where in kharif 2022-23, maize production was 23.10 million tonnes in an area of 9.68 million hectares (agricoop.nic.in). Crop plants can interact with microbes to improve their defenses, development, and growth Nosheen *et al*., [3]. Further, more consistent positive results may be obtained by inoculating plants with microbial consortia containing two or more beneficial microorganisms [4]. Bioinoculants based on microbial consortia may include bacteria of different species, while others may include both beneficial bacteria and fungi [5].

2. MATERIALS AND METHODS

Field experiment on maize crop was conducted during *kharif* 22 at Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (MS), India on Vertisol to find out the influence of microbial inoculants and their consortia on yield and nutrient uptake in maize grown on Vertisol. Ten treatments were used in the experiment, viz. T_1 Absolute control, T_2 Recommended Dose of Fertilizer (RDF), T_3 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* , T_4 Recommended Dose of Fertilizer RDF + *Azospirillum lipoferum* + *Bacillus megaterium* (PSB), T_5 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipopherum* + *Frateuria aurantia (* KSB), T_6 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipopherum* + *Thiobacillus thiooxidans (* SSB), T_7 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Pseudomonas striata (* ZnSB), T_8 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Bacillus megaterium* (PSB) + *Frateuria aurantia (* BCC), T_9 Recommended Dose of Fertilizer (RDF) + *Azospirillum lipopherum* + *Bacillus megaterium(* PSB) + *Thiobacillus thiooxidans* (SSB), T_{10} Recommended Dose of Fertilizer (RDF) + *Azospirillum lipopherum* + *Bacillus megaterium* (PSB) + *Pseudomonas striata* (ZnSB), the experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. Seeds were sown at the rate of 15 kg ha $^{-1}$ for maize. The fertilizers were applied @ N: P_2O_5: K_2O 120:60:40 kg ha $^{-1}$ respectively. Urea, single super phosphate and muriate of potash were used as fertilizer sources. *Azospirillum lipoferum* with *Bacillus megaterium* (Consortia-I), *Azospirillum lipoferum* with *Frateuria aurantia* (Consortia-II), *Azospirillum lipoferum* with *Thiobacillus thiooxidans* (Consortia-III), *Azospirillum lipoferum* with *Pseudomonas striata* (Consortia-IV), *Azospirillum lipoferum* with *Bacillus megaterium* and *Frateuria aurantia* (Consortia-V), *Azospirillum lipoferum* with *Bacillus megaterium* and *Thiobacillus thiooxidans* (Consortia-VI), *Azospirillum lipoferum* with *Bacillus megaterium* and *Pseudomonas striata* (Consortia-VII) were obtained from ICAR - All India Network Project on Soil Biodiversity – Biofertilizers, Parbhani Center and used for seed treatment @ 10 ml per kg of maize seed. Seed treatment was done before sowing. Seeds were dried in shed and used for sowing as dibbling.

3. RESULTS AND DISCUSSION

3.1 Grain and Straw Yield

The grain yield of maize was observed maximum *ie.*, 8156.00 kg ha $^{-1}$ in treatment T_{10} RDF + *Azospirillum* + PSB + ZnSB , (Consortia-VII)

followed by treatment T_9 RDF + *Azospirillum* + PSB + SSB, (Consortia-VI), (7587 .33 kg ha $^{-1}$). Significantly lowest grain yield was observed in T_1 (absolute control). And straw yield significantly highest (9836.33 kg ha $^{-1}$) was obtained from treatment receiving T_{10} RDF + *Azospirillum* + PSB + ZnSB (Consortia-VII) followed by treatment T_9 RDF + *Azospirillum* + PSB + SSB (Consortia-VI) (Table 1). Yadav *et al.,* [6] reported that application of Azotobacter and PSB to the pearl millet hybrid MLBH-308 produced the highest stover output in the sandy soil and 20.5% increase in grain yield compared to the control. Chhagan *et al.* [7] also reported that the higher yield under microbial inoculated plants might be due to balanced addition of NPK, and integrated effect of organic, inorganic and biofertilizer which enhanced nutrients availability and resulted in improved grain. Gao *et al*. [8] reported that the application of the organic and biofertilizers besides 50% NPK has improved the maize yield parameters as compared with the control plants. Biofertilizers facilitate the overall growth and yield of crops in an eco-friendly manner. They contain living or dormant microbes, which are applied to the soil or used for treating crop seeds [9].

3.2 Major Nutrient (NPK) Uptake in Grain and Straw (kg ha $^{-1}$) of Maize

Nutrient uptake (NPK) of maize was significantly influenced by microbial inoculants and their consortia with RDF. The grain NPK uptake ranges from 57 to 203.08; 7.73 to 35.07 and 8.58 to 64.92 kg ha $^{-1}$ during kharif 22. However, the NPK uptake of straw varied from 84.40 to 192.64; 22.93 to 64.92 and 55.81 to 137.22 kg ha $^{-1}$ total uptake of NPK was ranged from 141.58 to 395.72; 30.66 to 99.99 and 64.40 to 170.65 kg ha $^{-1}$ and statistically significant values in treatment T_{10} (RDF + *Azospirillum* + PSB + ZnSB) followed by treatment T_9 (RDF + *Azospirillum* + PSB + SSB) the nutrient uptake variation among the treatments showed the effect of microbial inoculants and their consortia to increase both grain and straw of maize. The enhancement is due to the length and quantity of plant roots which might have been boosted by microbes that create phytohormones, which in turn raised the concentration of nutrients in the soil Qureshi *et al.,* [10] and ultimately their uptake by the crop. Kumar *et al.* [11] also reported the impact of seed bacterization with PGPR on growth and nutrient uptake in a variety of cultivable varieties of green gram. Bagmare *et al.* [12] reported that the rhizosphere the soil environment where the plant root is available and is a zone of maximum microbial activity resulting in a confined nutrient pool in which essential macro and micronutrients are extracted. Plant growth regulators, also termed plant exogenous hormones, are synthetic substances that are similar to natural plant hormones. One of the terms for the prominent modes of action for growth promotion by PGPR is Phyto stimulation or plant growth regulator. They are used to regulate the growth of plants and are important measures for boosting agricultural production. Gao *et al*. [8] reported that the interaction between the organic and biofertilizers resulted in enhanced nutrient uptake specifically N content which could contribute to increasing amino acids content and thus the protein content of the maize grains. Sahu *et al*. [13] found that seed inoculation with KSB improved crop growth, yield, plant height and also increased grain and shoot weight which has improved better uptake of potassium by crop from soil.

Table 1. Effect of microbial inoculants and their consortia on grain and straw yield of maize

Tr. No.	Treatments	Grain yield (kg ha $^{-1}$)	Straw yield (kg ha $^{-1}$)
T_1	Absolute control	3365.00	5834.33
T_2	RDF	4717.00	7552.33
T_3	T_2 + *Azospirillum*	4862.66	8518.33
T_4	T_2 + *Azospirillum* + PSB	6772.66	8790.33
T_5	T_2 + *Azospirillum* + KSB	6828.66	8993.33
T_6	T_2 + *Azospirillum* + SSB	7153.33	8906.66
T_7	T_2 + *Azospirillum* + ZnSB	6802.00	8564.33
T_8	T_2 + *Azospirillum* + PSB + KSB	7211.33	9247.00
T_9	T_2 + *Azospirillum* + PSB + SSB	7587.33	9543.00
T_{10}	T_2 + *Azospirillum* + PSB + ZnSB	8156.00	9836.66
	SEM ±	30.54	56.91
	CD at 5%	90.76	169.10
	CV%	1.08	1.15

Table 2. Effect of microbial inoculants and their consortia on nitrogen uptake of maize straw and grain

Tr.No.	Treatments	N uptake (kg ha $^{-1}$)			P uptake (kg ha $^{-1}$)			K uptake (kg ha $^{-1}$)		
		Grains	Straw	Total	Grains	Straw	Total	Grains	Straw	Total
T_1	Absolute control	57.18	84.40	141.58	7.73	22.93	30.66	8.58	55.81	64.40
T_2	RDF	94.46	124.74	219.19	16.03	42.82	58.85	16.96	86.85	103.81
T_3	T2 + *Azospirillum*	93.61	142.25	235.86	18.51	54.85	73.36	18.40	81.93	100.33
T_4	T2 + *Azospirillum* + PSB	141.87	161.46	303.00	30.47	68.48	98.95	27.76	113.11	140.87
T_5	T2 + *Azospirillum* + KSB	166.53	158.12	321.32	25.26	56.68	81.94	30.72	127.46	158.18
T_6	T2 + *Azospirillum* + SSB	169.86	164.31	333.84	27.89	61.21	89.10	28.61	114.89	142.61
T_7	T2 + *Azospirillum* + ZnSB	136.72	154.16	290.88	23.12	53.87	77.61	25.84	107.28	133.12
T_8	T2 + *Azospirillum* + PSB + KSB	170.90	174.43	345.33	29.56	64.45	94.01	30.67	128.81	159.81
T_9	T2 + *Azospirillum* + PSB + SSB	181.33	184.96	366.29	31.10	67.16	98.26	31.10	133.18	168.65
T_{10}	T2 + *Azospirillum* + PSB + ZnSB	203.08	192.64	395.72	35.07	64.92	99.99	33.43	137.22	170.65
	SEM ±	5.38	5.04	6.74	0.95	3.98	2.25	0.95	9.22	4.12
	CD at 5%	15.98	14.96	20.03	2.81	11.82	6.67	2.81	27.62	12.24
	CV%	6.75	1.70	3.95	6.52	6.33	4.85	6.52	14.72	5.32

Table 3. Effect of microbial inoculants and their consortia on iron and manganese uptake of maize straw and grain

Tr. No.	Treatments	Fe uptake (g ha $^{-1}$)			Mn uptake (g ha $^{-1}$)		
		Grains	Straw	Total	Grains	Straw	Total
T_1	Absolute control	685.34	865.03	1550.37	234.43	356.09	590.52
T_2	RDF	1186.88	1349.42	2535.63	508.02	490.67	998.69
T_3	T2+ *Azospirillum*	1209.19	1522.99	2732.18	551.94	581.58	1132.85
T_4	T2 + *Azospirillum* + PSB	1727.56	1595.12	3332.35	783.41	595.71	1380.45
T_5	T2+ *Azospirillum* + KSB	1734.68	1635.40	3370.08	788.49	624.45	1412.27
T_6	T2+ *Azospirillum* + SSB	1827.91	1643.97	3470.21	833.57	609.57	1443.14
T_7	T2+ *Azospirillum* + ZnSB	1750.83	1587.26	3338.09	818.48	608.04	1426.52
T_8	T2+ *Azospirillum* + PSB + KSB	1870.88	1746.75	3618.30	890.09	675.65	1565.74
T_9	T2+ *Azospirillum* + PSB + SSB	1974.22	1833.35	3807.57	956.98	705.38	1662.36
T_{10}	T2+ *Azospirillum* + PSB + ZnSB	2135.81	1881.42	4017.23	993.40	688.23	1681.63
	SEM ±	30.47	30.98	39.66	16.54	11.46	14.86
	CD at 5%	90.55	92.04	117.83	49.14	34.04	44.14
	CV%	3.28	3.43	2.16	3.89	3.34	1.94

Table 4. Effect of microbial inoculants and their consortia on nitrogen uptake of maize straw and grain

Tr. No.	Treatments	Zn uptake (g ha $^{-1}$)			Cu uptake (g ha $^{-1}$)		
		Grains	Straw	Total	Grains	Straw	Total
T_1	Absolute control	130.94	29.47	31.89	61.36	129.94	260.67
T_2	RDF	206.56	50.94	57.14	108.08	322.20	528.76
T_3	T2+ *Azospirillum*	228.37	55.19	67.87	123.06	384.04	612.41
T_4	T2 + *Azospirillum* + PSB	318.92	79.24	74.14	153.38	393.26	712.18
T_5	T2+ *Azospirillum* + KSB	315.82	82.62	77.91	160.53	412.82	728.64
T_6	T2+ *Azospirillum* + SSB	340.08	83.19	80.47	163.66	405.60	745.68
T_7	T2+ *Azospirillum* + ZnSB	348.60	84.82	80.80	165.62	428.52	777.12
T_8	T2+ *Azospirillum* + PSB + KSB	348.09	94.46	91.54	186.00	450.74	801.50
T_9	T2+ *Azospirillum* + PSB + SSB	372.73	103.00	99.84	202.99	471.00	844.47
T_{10}	T2+ *Azospirillum* + PSB + ZnSB	404.70	105.45	96.10	201.55	485.27	889.97
	SEM ±	10.09	1.44	2.30	3.08	8.02	13.14
	CD at 5%	29.97	4.28	6.83	9.14	23.83	39.03
	CV%	5.80	3.24	5.25	3.49	3.58	3.30

3.3 Iron and Manganese Uptake (g ha $^{-1}$)

The highest uptake values of iron in maize grain-ie 2135.81 g ha $^{-1}$, straw-1881.42 g ha $^{-1}$ and total- 4017.23 g ha $^{-1}$ were found statistically significantly high showing maximum values in treatment T_{10} (RDF + *Azospirillum* + PSB + ZnSB) followed by treatment T_9 (RDF + *Azospirillum* + PSB + SSB) has iron uptake grain-1974.22 g ha $^{-1}$, straw-1833.35 g ha $^{-1}$ and total- 3807.57 g ha $^{-1}$. Whereas, uptake of iron noticed lowest in treatment T_1 (absolute control) *ie* ., grain- 680.03 g ha $^{-1}$, straw-865.03 g ha $^{-1}$ and total-1550.37 g ha $^{-1}$. Kumar *et al.* [14] showed that coinoculation of *Rhizobium* and *Trichoderma viride* along with RDF enhanced the yield, nutrient content, nutrient uptake and quality of soybean crop. Bagmare *et al.* [12] reported that biofortification of Zn by plant growth promoting microorganisms in wheat straw and grains respectively. The zinc concentration in leaves and straw was enhanced due to the coinoculation of different plant growth promoting microorganisms in wheat. The Zinc concentration of leaves was periodically estimated at tillering, flowering and at harvest of crop in both seasons Rabi 2020-21, 2021-22 and pooled mean was calculated.

The maximum uptake of manganese grain-993.40 g ha $^{-1}$, straw- 688.23 g ha $^{-1}$ and total-1681.63 kg ha $^{-1}$ by maize were found statically significant showing maximum values in treatment T_0 (RDF+ *Azospirillum* + PSB + ZnSB), followed by treatment T_9 (RDF+ *Azospirillum* + PSB + SSB) grain- 956.98 g ha $^{-1}$, straw- 705.38 g ha $^{-1}$ and total- 1662.36 g ha $^{-1}$ and T8 RDF+ *Azospirillum* + PSB + SSB) uptake grain- 890.09 g ha $^{-1}$, straw- 675.65 g ha $^{-1}$ and total- 1565.74 g ha $^{-1}$. However, uptake of manganese recorded lowest value in treatment T_1 (absolute control) *ie,* grain- 234.43 g ha $^{-1}$, straw- 356.09 g ha $^{-1}$ and total- 590.52 g ha $^{-1}$. Gamit and Tank [15] reported that inoculating *Cajanas cajan* with *Pseudomonas pseudoalcaligenes* which produces siderophore, due to acidification of PGPR it enhances the uptake of Fe, Cu, Mn, Zn, Co, Ni and Al. The role of microbial isolates boosts the growth of plants.

3.4 Zinc and Copper Uptake (g ha $^{-1}$)

The highest uptake of zinc grain- 404.70 g ha $^{-1}$, straw- 485.27 g ha $^{-1}$ and total- 889.97 kg ha $^{-1}$ by maize were found statistically significant showing maximum values in treatment T_{10} (RDF + *Azospirillum* + PSB + ZnSB) which was followed by treatment T_9 (RDF *Azospirillum* + PSB + SSB) has zinc uptake grain-373.06 g ha $^{-1}$, straw- 471.00 g ha $^{-1}$ and total- 844.47 g ha $^{-1}$. However, uptake of zinc was recorded lowest value in treatment T_1 *ie* ., absolute control grain-130.73 g ha $^{-1}$, straw- 129.94 g ha $^{-1}$ and total-260.67 g ha $^{-1}$. According to Jadhav [16] there was a statistically significant interaction between zinc solubilizers and zinc levels. The results showed that Pseudomonas striata treatment with 30 kg $ZnSO_4$ ha $^{-1}$ had the maximum seed, straw, and total Zn uptake of pigeon pea.

Significantly highest uptake of copper grain-105.45 g ha $^{-1}$, straw- 99.99 g ha $^{-1}$ and total-205.44 kg ha $^{-1}$ by maize were found statistically significant showing maximum values in treatment

T_{10} (RDF + *Azospirillum* + PSB + ZnSB) followed by treatment T_9 (RDF + *Azospirillum* + PSB + SSB) has copper uptake grain- 103 g ha $^{-1}$, straw- 96.10 g ha $^{-1}$ and total- 199.10 g ha $^{-1}$ and T_8 (RDF + *Azospirillum* + PSB + KSB) has copper uptake grain- 94.46 g ha $^{-1}$, straw- 91.54 g ha $^{-1}$ and total- 186 g ha $^{-1}$ Whereas, uptake of copper recorded lowest value in treatment T_1 absolute control grain- 29.47 g ha $^{-1}$, straw- 31.89 g ha $^{-1}$ and total- 61.36 g ha $^{-1}$. Jayant Raman's [17-20] experiment revealed that the highest level of copper was created by combining the inoculation of *Pseudomonas striata*, *Trichoderma viride* and *Azotobacter chroococcum* [21-23].

4. CONCLUSION

The results of the investigation showed that the application of the *Azospirillum consortium lipoferum* + *Bacillus megaterium* + *Pseudomona strita* (Consortia -VII) as seed inoculation along with 100 per cent recommended dose of fertilizers performed as the best consortium for enhancing seed and stover yield of maize. Similarly for nutrient uptake of N, P and K, micronutrients *viz.* , Fe, Mn Cu and Zn.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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