

Original Research Article

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

ABSTRACT

The present field experiment was undertaken at Wheat and Maize Research Unit, Vasantnaik Marathwada Krishi Vidyapeeth, Parbhani during *Kharif* season of 2022. Ten different treatment combinations were used in the experiment which includes different microbial inoculants and their consortia i.e. *Azospirillum* + *Bacillus megaterium* (Consortia-I), *Azospirillum* + *Frateuria aurantia* (Consortia-II), *Azospirillum* + *Thiobacillus thiooxidans* (Consortia-III), *Azospirillum* + *Pseudomonas striata* (Consortia-IV), *Azospirillum* + *Bacillus megaterium* + *Frateuria aurantia* (Consortia-V), *Azospirillum* + *Bacillus megaterium* + *Thiobacillus thiooxidans* (Consortia-VI), *Azospirillum* + *Bacillus megaterium* + *Pseudomonas striata* (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 thiooxidans* (Consortia-VII) noted significantly higher grain and stover yield of maize (8156.00 and 9836.66 kg ha⁻¹ respectively). Further, 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, Compatibility.

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 than wheat or rice crop 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.* 2021). It is cultivated in nearly 205 million ha with a production of 1210 million tones and productivity of 5878 kg/ha all over the world, having wider diversity of soil, climate, biodiversity and management practices (FAOSTAT, 2021). Where in kharif 2022-23, maize production was 23.10 million tones 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.*, 2021). Further, more consistent positive results may be obtained by inoculating plants with microbial consortia containing two or more beneficial microorganisms (Sharma *et al.*, 2020). Bioinoculants based on microbial consortia may include bacteria of different species, while others may include both beneficial bacteria and fungi (Zang *et al.*, 2018).

MATERIAL AND METHODS

Field experiment on maize crop was conducted during *kharif* 22 at Wheat and Maize Research Unit, Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani (M.S.), 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. T₁ Absolute control, T₂ Recommended Dose of Fertilizer (RDF), T₃ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum*, T₄ Recommended Dose of Fertilizer RDF + *Azospirillum lipoferum* + *Bacillus megaterium* (PSB), T₅ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Frateuria aurantia* (KSB), T₆ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Thiobacillus thiooxidans* (SSB), T₇ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Pseudomonas striata* (ZnSB), T₈ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Bacillus megaterium* (PSB) + *Frateuria aurantia* (KSB), T₉ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *Bacillus megaterium* (PSB) + *Thiobacillus thiooxidans* (SSB), T₁₀ Recommended Dose of Fertilizer (RDF) + *Azospirillum lipoferum* + *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: P₂O₅: K₂O 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 Centre 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.

RESULTS AND DISCUSSION

Grain and Straw Yield

The grain yield of maize was observed maximum *i.e.*, 8156.00 kg ha⁻¹ in treatment T₁₀ RDF + *Azospirillum* + PSB + ZnSB, (Consortia-VII) followed by treatment T₉ RDF + *Azospirillum* + PSB + SSB, (Consortia-VI), (7587.33 kg ha⁻¹). Significantly lowest grain yield was observed in T₁ (absolute control). And straw yield significantly highest (9836.33 kg ha⁻¹) was obtained from treatment receiving T₁₀ RDF + *Azospirillum* + PSB + ZnSB (Consortia-VII) followed by treatment T₉ RDF + *Azospirillum* + PSB + SSB (Consortia-VI) (Table 1). Yadav *et al.*, (2016) 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.* (2019) 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 improvement grain. Gao *et al.* (2020) reported that the application of the organic and biofertilizers beside 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 (Basu *et al.*,2021).

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 + <i>Azospirillum</i>	4862.66	8518.33
T ₄	T ₂ + <i>Azospirillum</i> + PSB	6772.66	8790.33
T ₅	T ₂ + <i>Azospirillum</i> + KSB	6828.66	8993.33
T ₆	T ₂ + <i>Azospirillum</i> + SSB	7153.33	8906.66
T ₇	T ₂ + <i>Azospirillum</i> + ZnSB	6802.00	8564.33
T ₈	T ₂ + <i>Azospirillum</i> + PSB + KSB	7211.33	9247.00
T ₉	T ₂ + <i>Azospirillum</i> + PSB + SSB	7587.33	9543.00
T ₁₀	T ₂ + <i>Azospirillum</i> + PSB + ZnSB	8156.00	9836.66
	SEm±	30.54	56.91
	C.D. at 5%	90.76	169.10
	C.V.%	1.08	1.15

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 ranged 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 T₁₀ (RDF+ *Azospirillum* + PSB + ZnSB) followed by treatment T₉ (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 boosted by microbes that create phytohormones, which in turn raised the concentration of nutrients in the soil (Qureshi *et al.*, 2011) and ultimately their uptake by the crop. Kumar *et al.* (2015) also reported the impact of seed bacterization with PGPR on growth and nutrient uptake in a variety of cultivable varieties of green gramme. Bagmare *et al.* (2023) 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.* (2020) reported that the interaction between the organic and biofertilizers resulted in enhanced nutrients uptake specifically N content which could contribute to increasing amino acids content and thereby the protein content of the maize grains. Sahu *et al.* (2021) found that seed inoculation with KSB which improved crop growth, yield, plant height and also increased of grain and shoot weight which have improved better uptake of potassium by crop from soil.

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)		
		Grain	Straw	Total	Grain	Straw	Total	Grain	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	T ₂ + <i>Azospirillum</i>	93.61	142.25	235.86	18.51	54.85	73.36	18.40	81.93	100.33
T ₄	T ₂ + <i>Azospirillum</i> + PSB	141.87	161.46	303.00	30.47	68.48	98.95	27.76	113.11	140.87
T ₅	T ₂ + <i>Azospirillum</i> + KSB	166.53	158.12	321.32	25.26	56.68	81.94	30.72	127.46	158.18
T ₆	T ₂ + <i>Azospirillum</i> + SSB	169.86	164.31	333.84	27.89	61.21	89.10	28.61	114.89	142.61
T ₇	T ₂ + <i>Azospirillum</i> + ZnSB	136.72	154.16	290.88	23.12	53.87	77.61	25.84	107.28	133.12
T ₈	T ₂ + <i>Azospirillum</i> + PSB + KSB	170.90	174.43	345.33	29.56	64.45	94.01	30.67	128.81	159.81
T ₉	T ₂ + <i>Azospirillum</i> +	181.33	184.96	366.29	31.10	67.16	98.26	31.10	133.18	168.65

	PSB + SSB									
T ₁₀	T2 + <i>Azospirillum</i> + 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
	C.D. at 5%	15.98	14.96	20.03	2.81	11.82	6.67	2.81	27.62	12.24
	C.V.%	6.75	1.70	3.95	6.52	6.33	4.85	6.52	14.72	5.32

Iron and manganese uptake (g ha⁻¹)

The highest uptake values of iron in maize grain- i.e. 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 T₁₀ (RDF+ *Azospirillum* + PSB + ZnSB) followed by treatment T₉ (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 T₁ (absolute control) i.e., grain- 680.03 g ha⁻¹, straw-865.03 g ha⁻¹ and total-1550.37 g ha⁻¹. Kumar *et al.* (2016) showed that coinoculation of *Rhizobium* and *Trichoderma viride* along with RDF enhanced the yield, nutrients content, nutrient uptake and quality of soybean crop. Bagmare *et al.* (2023) 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 estimated periodically at tillering, flowering and at harvest of crop in both seasons Rabi 2020-21, 2021-22 and pooled mean was calculated.

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

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No.	Treatments	Fe uptake (g ha ⁻¹)			Mn uptake (g ha ⁻¹)		
		Grain	Straw	Total	Grain	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	T ₂ + <i>Azospirillum</i>	1209.19	1522.99	2732.18	551.94	581.58	1132.85
T ₄	T ₂ + <i>Azospirillum</i> + PSB	1727.56	1595.12	3332.35	783.41	595.71	1380.45
T ₅	T ₂ + <i>Azospirillum</i> + KSB	1734.68	1635.40	3370.08	788.49	624.45	1412.27
T ₆	T ₂ + <i>Azospirillum</i> + SSB	1827.91	1643.97	3470.21	833.57	609.57	1443.14
T ₇	T ₂ + <i>Azospirillum</i> + ZnSB	1750.83	1587.26	3338.09	818.48	608.04	1426.52
T ₈	T ₂ + <i>Azospirillum</i> + PSB + KSB	1870.88	1746.75	3618.30	890.09	675.65	1565.74
T ₉	T ₂ + <i>Azospirillum</i> + PSB + SSB	1974.22	1833.35	3807.57	956.98	705.38	1662.36
T ₁₀	T ₂ + <i>Azospirillum</i> + 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
	C.D. at 5%	90.55	92.04	117.83	49.14	34.04	44.14
	C.V.%	3.28	3.43	2.16	3.89	3.34	1.94

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 T₀ (RDF+ *Azospirillum* + PSB + ZnSB), followed by treatment T₉ (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. Whereas, uptake of manganese recorded lowest value in treatment T₁ (absolute control) *i.e.*, grain- 234.43 g ha⁻¹, straw- 356.09 g ha⁻¹ and total- 590.52 g ha⁻¹. Gamit and Tank (2014) reported that inoculating *Cajanas cajan* with *Pseudomonas pseudoalcaligenes* which produces siderophore, due to acidification of PGPR it enhanced the uptake of Fe, Cu, Mn, Zn, Co, Ni and Al. The role of microbial isolates boosts the growth of plant.

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 T₁₀ (RDF + *Azospirillum* +PSB + ZnSB) which was followed by treatment T₉ (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. Whereas, uptake of zinc was recorded lowest value in treatment T₁ *i.e.*, absolute control grain- 130.73 g ha⁻¹, straw- 129.94 g ha⁻¹ and total- 260.67 g ha⁻¹. According to Jadhav (2021), there was a statistically significant interaction between zinc solubilizers and zinc levels. The results showed that *Pseudomonas striata* treatment with 30 kg ZnSO₄ 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 T₁₀ (RDF + *Azospirillum* + PSB + ZnSB) followed by treatment T₉ (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 T₈ (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 T₁ absolute control grain- 29.47 g ha⁻¹, straw- 31.89 g ha⁻¹ and total- 61.36 g ha⁻¹. Jayant Raman's (2012) experiment revealed that the highest level of copper was created by combining the inoculation of *Pseudomonas striata*, *Trichoderma viride* and *Azotobacter chroococcum*.

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)		
		Grain	Straw	Total	Grain	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+ <i>Azospirillum</i>	228.37	55.19	67.87	123.06	384.04	612.41
T ₄	T2+ <i>Azospirillum</i> + PSB	318.92	79.24	74.14	153.38	393.26	712.18
T ₅	T2+ <i>Azospirillum</i> + 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
	C.D. at 5%	29.97	4.28	6.83	9.14	23.83	39.03
	C.V.%	5.80	3.24	5.25	3.49	3.58	3.30

Conclusion:

The result of the investigation showed that the application of consortium *Azospirillum 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.

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