



Impact of Biofertilizers and Inorganic Fertilizers on Micronutrient Content and Uptake of Maize (*Zea mays* L)

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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

This study aims to investigate the effect of fertilizers mixed with biofertilizers on maize crop micronutrient uptake. The study was conducted on clay loam soils at Agriculture College Farm, Bapatla, during both kharif 2020 and 2021. The results indicated that application of 100% RDF +VAM + Azospirillum + PSB recorded highest micronutrient content and lowest recorded with the control, but non-significantly influenced by the imposed treatments at knee-high, tasseling and harvest stage (straw and grain) of maize crop. The application of 100% RDF +VAM + Azospirillum + PSB recorded significantly ($P < 0.05$) highest iron, manganese, copper and zinc uptake at knee-high, tasseling and harvest stage of maize crop. The results revealed that application of biofertilizers along with inorganic fertilizers significantly increased plant nutrient content and uptake of maize crop. In conclusion, the study suggested that integrated use of biofertilizers and inorganic fertilizers improves the nutrient content and uptake of maize crop.

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Keywords: Biofertilizers; fertilizer levels; micronutrient content; uptake.

1. INTRODUCTION

Maize (*Zea mays* L) 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. It is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes 36 % (782 m t) in the global grain production [1-3]. In India, maize is the third most important food crops after rice and wheat. In India, maize contributes nearly 9 % of the national food basket. In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material for thousands of industrial products including starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc. Maize is cultivated both in temperate and tropical regions of the world. The full yield potential of maize crop can be exploited through adoption of hybrids with better nitrogen management practices (DoES-2020-21).

The application of biofertilizers (PSB, *Azospirillum* and VAM) plays a vital role in solubilization of various inorganic and organic phosphates added to the soil. It may also release soluble phosphorus into the soil through the decomposition of phosphorus from organic compounds. The use of microbial inoculation can reduce the dosage of inorganic fertilizer, increase the nutrient content that can be absorbed from the soil, increase crop productivity and improve the quality of land sustainably [4]. There is a difference in biofertilizer performance among different crops out of which climate, soil biodiversity, soil fertility and soil C:N ratio are major contributing factors. Thus, the need for biofertilizers in nutrient content and uptake is an important factor in many soils [5].

2. MATERIALS AND METHODS

2.1 Site Description

The field experiment was carried out during both *kharif* seasons of 2020-2021 at Agricultural College Farm, Bapatla, located at an altitude of 5.49 m above mean sea level, 15°54' North latitude, 80°30' East longitude and about 8 km away from Bay of Bengal. It is in Krishna agro-climatic zone of Andhra Pradesh. The

experimental soil was clay loam in texture, slightly alkaline in reaction (pH 7.56), non- saline (0.64 dS m⁻¹), medium in organic carbon (5.4 g kg⁻¹), medium in available nitrogen (283 kg ha⁻¹), medium in available phosphorus (42.5 kg ha⁻¹), high in potassium (426 kg ha⁻¹) and medium in sulphur (14.3 mg kg⁻¹) and sufficient in all micronutrients Fe(6.81 mg kg⁻¹), Mn (5.43 mg kg⁻¹), Cu (1.37 mg kg⁻¹) and Zn (0.58 mg kg⁻¹).

2.2 Experimental Design and Treatments

The experiment was laid out in randomized block design (RBD) with seven treatments and replicated thrice. The experimental treatment details are as following T₁- control, T₂- 100% RDF, T₃- 125% RDF, T₄- 100% RDF + VAM, T₅- 100% RDF +VAM + *Azospirillum* + PSB, T₆- 75 % RDF + VAM, T₇- 75 % RDF + VAM + *Azospirillum* + PSB. RDF for maize 200:60:50 kg ha⁻¹ N, P₂O₅ and K₂O through applied urea, single super phosphate and muriate of potash and biofertilizers like VAM -12.5 kg ha⁻¹, *Azospirillum* -5 kg ha⁻¹ and PSB -5 kg ha⁻¹ through applied vermicompost. The popular hybrid of maize Pioneer 3396 was chosen for the study.

2.3 Collection and Preparation of Plant Samples

Plant samples of maize was collected from five randomly selected plants at knee high, tasseling and harvest stage. The samples were first dried in shade and then in hot air oven at 65 °C. The plant samples were ground in willey mill and stored in labeled brown paper bags for analysis. The grain samples were also processed and stored in similar fashion.

2.4 Methods Used for Plant Analysis

Di-acid extract was prepared as per the method outlined by Jackson [6]. It was carried out using a 9:4 mixture of HNO₃: HClO₄. The pre digestion of sample was done by using 10ml of HNO₃ g⁻¹ sample. Iron, manganese, copper and zinc in the diacid extract were determined using atomic absorption spectrophotometer as per the specifications mentioned by Lindsay and Norvell [7]. From the chemical analytical data, uptake of each nutrient was calculated as shown below.

2.5 Micronutrient Uptake by Maize Crop

From the chemical analytical data, uptake of the micronutrients at knee high, tasseling and

harvest of the maize crop was calculated and expressed by using the formulae.

$$\text{Micronutrient uptake (g ha}^{-1}\text{)} = \frac{\text{Nutrient content (mg kg}^{-1}\text{)} \times \text{dry weight in kg ha}^{-1}}{1000}$$

3. RESULTS AND DISCUSSION

3.1 Micronutrient Content

3.1.1 Iron content

The results revealed that, different levels of fertilizers and biofertilizer treatments applied to maize has a non- significant influence on iron content (Table 1). Irrespective of the growth stages of maize and during both the years of study, application of 100% RDF + VAM + *Azospirillum* and PSB (T₅) (106.37, 92.16, 58.48, 46.84 mg kg⁻¹ in 2020 and 113.07, 100.15, 60.15, 47.77 mg kg⁻¹ in 2021) recorded numerically higher iron content at knee high, tasseling and harvest (stover and grain) stages of maize crop growth, respectively. The lowest iron content was recorded with the treatment T₁ (74.12, 65.32, 36.81, 31.94 mg kg⁻¹ in 2020 and 80.55, 70.16, 38.19, 28.70 mg kg⁻¹ in 2021). This might be due to the application biofertilizer and inorganics which slightly increased iron content at all the stages of crop growth. There was no significant influence on micronutrient contents with combined application of inorganics along with biofertilizers [8]. Irrespective of the year of the study, the Fe content in maize decreased with the growth stages from knee high to harvest stage.

3.1.2 Manganese content

Numerically, higher manganese content values were recorded in application of 100% RDF + VAM + *Azospirillum* and PSB (T₅) (49.77, 45.37, 29.40, 16.18 mg kg⁻¹ in 2020 and 52.77, 46.42, 31.43, 16.73 mg kg⁻¹ in 2021) at knee high, tasseling and harvest (stover and grain) stages of maize crop growth, respectively (Table 2). The lowest manganese content was recorded with the treatment T₁ (34.34, 31.11, 18.53, 10.16 mg kg⁻¹ in 2020 and 37.08, 32.42, 19.37, 10.86 mg kg⁻¹ in 2021). The results of the present study revealed that the combined application of biofertilizers and inorganic fertilizers recorded the highest manganese content compared to control. There was no significant influence on micronutrient contents with combined application of inorganics along with biofertilizers [8]. Irrespective of the year of study, the Mn content in maize straw decreased with the advancement of crop growth from knee high to harvest

indicating the dilution effect [9]. The wide variation in Mn concentration between straw and grain might be due to the slow movement of Mn from straw to grain as reported by Duhan and Singh [10].

3.1.3 Copper content

Irrespective of the growth stages of maize during both the years of the study, application of 100% RDF + VAM + *Azospirillum* and PSB (T₅) (18.15,14.76,12.68,7.23 mg kg⁻¹ in 2020 and 20.22,15.62,12.96,7.55 mg kg⁻¹ in 2021) at knee high, tasseling and harvest (stover and grain) stages of maize crop growth, respectively (Table 3). The lowest copper content was recorded with the treatment T₁ (10.47,9.41,7.06,5.05 mg kg⁻¹ in 2020 and 13.69,10.50,8.67,4.52 mg kg⁻¹ in 2021). The results of the present study revealed that the combined application of biofertilizers and inorganic fertilizers recorded numerically higher copper content compared to control. There was no significant influence on micronutrient contents with combined application of inorganics along with biofertilizers [8]. Irrespective of the year of the study, the Cu content in maize decreased with the growth stage from knee high to tasseling stage. When compared to Cu content in grain and straw at harvest was higher in all treatments.

3.1.4 Zinc content

The higher zinc content values were recorded in 100% RDF + VAM + *Azospirillum* and PSB (T₅) (43.43, 37.15, 34.26, 31.60 mg kg⁻¹ in 2020 and 45.85, 39.52, 34.74, 31.82 mg kg⁻¹ in 2021) at knee high, tasseling and harvest (stover and grain) stages of maize crop growth, respectively (Table 4). The lowest zinc content was recorded with the treatment T₁ (29.18, 26.84, 24.42, 21.25 mg kg⁻¹ in 2020 and 31.07, 27.93, 24.63, 22.33 mg kg⁻¹ in 2021) which received no fertilizers at knee high, tasseling and harvest (stover and grain) stages of maize crop growth. Increase in concentration of zinc with application of inorganics along with the biofertilizers was probably due to chelation of zinc with organic ligands, which might have enhanced the availability of zinc and its absorption by the plants. Zinc content was slightly increased but non significantly influenced by the treatments. Irrespective of the year of study, the Zn content in maize decreased with the growth stage from knee high to tasseling due to dilution effect and the Zn content in grain was lower when compared to straw. The decreased zinc content with the advancement of crop growth, could be due to the highest utilization of zinc in the

synthesis of some growth promoting hormones and in the reproductive processes of plants which were vital for grain formation.

3.2 Micronutrient Uptake

3.2.1 Iron uptake

Significantly higher Fe uptake was recorded in the treatment T₅ that received 100% RDF + VAM + *Azospirillum* and PSB (182.18, 655.19, 493.98, 287.29 g ha⁻¹ in 2020 and 205.00, 720.16, 519.62, 311.43 g ha⁻¹ in 2021) and it was on par with the treatments T₇, T₃ and T₄ at knee high, tasseling and harvest (straw and grain) stages of maize during 2020 and 2021, respectively (Table 5). The recommended dose of fertilizer T₂ (100% RDF) (123.69, 528.83, 365.44, 211.70 g ha⁻¹ in 2020 and 141.48, 575.00, 385.06, 225.82 g ha⁻¹ in 2021) was on par with T₃, T₄, T₆ and T₇ at knee high, tasseling and harvest (straw + grain) stages of maize crop, respectively. The lowest iron uptake was recorded with the treatment (T₁) control (73.74, 293.80, 192.06, 106.34 g ha⁻¹ in 2020 and 84.09, 322.52, 206.53, 110.60 g ha⁻¹ in 2021). The increase in the uptake of cationic micronutrients with application of organic manures and biofertilizers along with inorganic fertilizers might be due to release of micronutrients on mineralization or production of organic acids during their decomposition which aids in solubilization of insoluble micronutrient compounds in soil or due to supply of natural chelating agents which makes more availability and uptake of micronutrients [11]. The chelating action of released organic compounds prevent the micronutrient cations from fixation, precipitation, oxidation, leaching and increase their availability and uptake by plants. This is in accordance with results of Gogoi et al. [12]. The application of biofertilizer increased the uptake of both macro and micro nutrients. It was observed that biofertilizer application had enhanced plant nutrients uptake. The results are in close agreement with the findings of Mohammadi et al. [13] who demonstrated the ability of biofertilizers in increasing nutrient availability and uptake.

3.2.2 Manganese uptake

Among all the treatments, the highest Mn uptake in plant was recorded in the treatment T₅ i.e., 100% RDF + VAM + *Azospirillum* and PSB (85.24, 325.54, 249.40, 101.96 g ha⁻¹ in 2020 and 95.78, 336.45, 272.94, 109.91 g ha⁻¹ in 2021) and it was on par with the treatments T₇, T₃ and T₄ at knee high, tasseling and harvest (straw and grain) stages of maize during *kharif*, 2020 and 2021, respectively (Table 6). The

recommended dose of fertilizer T₂ (100% RDF) (55.31, 249.74, 187.56, 75.36 g ha⁻¹ in 2020 and 64.22, 263.71, 197.17, 82.62 g ha⁻¹ in 2021) was on par with T₃, T₄, T₆ and T₇ at knee high, tasseling and harvest (straw + grain) stages of maize crop. The lowest manganese uptake was recorded with the treatment T₁ (34.16, 135.43, 91.59, 39.35 g ha⁻¹ in 2020 and 38.70, 149.03, 104.75, 43.88 g ha⁻¹ in 2021). Application of inorganics in combination with biofertilizers might had increased the availability of Mn in soil thereby increased plant nutrient uptake [14]. It was observed that biofertilizer application had enhanced plant nutrients uptake. On the other hand, Mn uptake was gradually increased with advancement of stage of crop. Since dry matter production, yield and nutrient content were maximum or higher at harvest therefore significantly higher nutrient uptake is obvious [15].

3.2.3 Copper uptake

The results revealed that Cu uptake at different stages of maize was significantly influenced by different treatments imposed during both the years study (Table 7). The highest Cu uptake by the plant was recorded in the treatment T₅ i.e., 100% RDF + VAM + *Azospirillum* and PSB (31.62, 106.45, 108.03, 45.64 g ha⁻¹ in 2020 and 37.18, 114.13, 112.90, 49.88 g ha⁻¹ in 2021) and it was on par with T₇, T₃ and T₄ at knee high, tasseling and harvest (straw+ grain) stages of maize during *kharif*, 2020 and 2021, respectively. The recommended dose of fertilizer T₂ (100% RDF) (20.06, 80.07, 84.73, 28.01 g ha⁻¹ in 2020 and 24.90, 86.23, 87.40, 35.34 g ha⁻¹ in 2021) was on par with T₃, T₄, T₆ and T₇ at knee high, tasseling and harvest (straw + grain) stages of maize crop. The lowest copper uptake was recorded with the treatment (T₁) control (10.41, 38.95, 37.50, 17.11 g ha⁻¹ in 2020 and 14.07, 50.39, 46.57, 18.55 g ha⁻¹ in 2021). Application of inorganics in combination with biofertilizers are high which might had increased the availability of Cu in soil thereby increased plant nutrient uptake. Copper uptake was gradually increased with vegetative phase to harvest. When absorbed during the vegetative phase it helps in synthesizing the chlorophyll necessary for photosynthesis and promotes rapid leaf, stem and root growth which stimulates micronutrient absorption and assimilation of nutrients. The increased absorption of micronutrient cations also might be due to complexing properties of organics which prevent precipitation, fixation of these nutrients and keep them in soluble form [16].

Table 1. Effect of different levels of fertilizers in combination with biofertilizers on iron content (mg kg⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	74.12	65.32	36.81	31.94	80.55	70.16	38.19	28.70
T ₂ : 100% RDF	91.82	79.53	48.83	40.14	98.79	86.21	50.65	40.48
T ₃ : 125% RDF	103.83	89.26	53.67	43.47	107.13	96.10	53.94	44.13
T ₄ : 100% RDF + VAM	100.77	86.64	51.95	41.19	106.00	92.97	52.95	42.11
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	106.37	92.16	58.48	46.84	113.07	100.15	60.15	47.77
T ₆ : 75% RDF + VAM	87.62	75.59	47.79	35.80	95.56	81.25	48.43	39.46
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	104.10	90.18	55.47	44.43	111.76	97.84	56.47	45.16
SEm (±)	6.94	5.79	4.25	3.24	7.16	6.55	4.34	3.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	12.58	12.12	14.59	13.85	12.18	12.72	14.58	14.35

Table 2. Effect of different levels of fertilizers in combination with biofertilizers on manganese content (mg kg⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	34.34	31.11	18.53	10.16	37.08	32.42	19.37	10.86
T ₂ : 100% RDF	42.87	38.26	24.99	13.83	45.91	40.27	25.89	14.11
T ₃ : 125% RDF	46.18	43.11	27.59	15.19	49.49	44.15	28.52	15.64
T ₄ : 100% RDF + VAM	44.93	41.47	26.90	14.76	47.25	42.50	27.92	14.76
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	49.77	45.37	29.40	16.18	52.77	46.42	31.43	16.73
T ₆ : 75% RDF + VAM	40.58	36.61	24.39	13.44	42.62	37.66	25.37	13.77
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	48.85	44.23	28.38	15.86	51.51	45.23	29.59	16.11
SEm (±)	3.53	2.96	2.11	1.20	3.22	3.12	2.28	1.18
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	13.91	12.79	14.17	14.61	11.95	13.06	14.22	14.05

Table 3. Effect of different levels of fertilizers in combination with biofertilizers on copper content (mg kg⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Kneehigh	Tasseling	Harvest		Kneehigh	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	10.47	9.41	7.06	5.05	13.69	10.50	8.67	4.52
T ₂ : 100% RDF	15.22	12.72	11.61	6.01	17.05	13.22	11.12	6.14
T ₃ : 125% RDF	16.93	13.30	12.20	6.74	17.76	14.51	12.41	7.16
T ₄ : 100% RDF + VAM	16.11	12.98	11.59	6.19	17.48	13.77	11.82	6.43
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	18.15	14.76	12.68	7.23	20.22	15.62	12.96	7.55
T ₆ : 75% RDF + VAM	14.51	11.68	10.55	5.46	15.61	12.32	10.71	5.63
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	17.20	14.22	12.47	7.10	18.64	14.85	12.59	7.31
SEm (±)	1.32	1.11	0.96	0.51	1.34	1.14	0.88	0.48
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	14.46	14.32	14.68	13.99	14.52	14.36	14.51	13.52

Table 4. Effect of different levels of fertilizers in combination with biofertilizers on zinc content (mg kg⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	29.18	26.84	24.42	21.25	31.07	27.93	24.63	22.33
T ₂ : 100% RDF	37.46	31.63	29.76	27.11	39.19	34.13	30.03	27.37
T ₃ : 125% RDF	40.34	35.95	32.88	29.27	43.18	37.08	33.23	29.55
T ₄ : 100% RDF + VAM	39.43	34.85	31.87	28.78	41.37	35.82	32.14	28.97
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	43.43	37.15	34.26	31.60	45.85	39.52	34.75	31.82
T ₆ : 75% RDF + VAM	36.21	31.23	29.74	26.74	37.43	32.36	30.07	26.93
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	41.19	36.36	33.58	30.15	43.85	38.35	33.88	31.06
SEm (±)	3.12	2.14	2.23	1.97	3.19	2.24	2.19	2.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	14.13	11.09	12.48	12.27	14.24	11.33	12.36	12.44

Table 5. Effect of different levels of fertilizers in combination with biofertilizers on iron uptake (g ha⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	73.74	293.80	192.06	106.34	84.09	322.52	206.53	110.60
T ₂ : 100% RDF	123.69	528.83	365.44	211.70	141.48	575.00	385.06	225.82
T ₃ : 125% RDF	158.09	594.36	426.37	250.91	177.91	650.00	434.68	273.87
T ₄ : 100% RDF + VAM	157.44	551.95	403.57	246.11	174.65	602.01	420.09	258.82
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	182.18	655.19	493.98	287.29	205.00	720.16	519.62	311.43
T ₆ : 75% RDF + VAM	102.24	446.31	318.34	183.52	122.90	482.01	328.01	176.90
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	170.10	626.01	451.90	269.74	194.33	684.41	468.69	283.45
SEm (±)	8.48	38.46	30.11	13.39	10.29	40.79	33.04	17.40
CD (P=0.05)	26.12	118.51	92.79	41.27	31.72	125.68	101.79	53.63
CV (%)	10.46	12.55	13.55	10.22	11.27	12.19	14.31	12.69

Table 6. Effect of different levels of fertilizers in combination with biofertilizers on manganese uptake (g ha⁻¹) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	34.16	135.43	91.59	39.35	38.70	149.03	104.75	43.88
T ₂ : 100% RDF	55.31	249.74	187.56	75.36	64.22	263.71	197.17	82.62
T ₃ : 125% RDF	74.57	293.78	219.08	84.76	84.04	300.81	229.65	95.89
T ₄ : 100% RDF + VAM	71.69	277.81	204.64	84.20	78.99	289.19	218.93	90.31
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	85.24	325.54	249.40	101.96	95.78	336.45	272.94	109.91
T ₆ : 75% RDF + VAM	49.36	222.51	163.58	63.20	57.04	231.83	172.97	68.51
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	80.04	310.84	230.56	90.36	89.31	317.87	243.63	100.89
SEm (±)	4.42	15.64	15.99	5.93	5.46	15.49	17.65	6.44
CD (P=0.05)	13.61	48.19	49.26	18.29	16.84	47.73	54.39	19.84
CV (%)	11.82	10.31	14.18	13.15	12.97	9.83	14.71	13.05

Table 7. Effect of different levels of fertilizers in combination with biofertilizers on copper uptake (g ha^{-1}) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	10.41	38.95	37.50	17.11	14.07	50.39	46.57	18.55
T ₂ : 100% RDF	20.06	80.07	84.73	28.01	24.90	86.23	87.40	35.34
T ₃ : 125% RDF	26.13	91.58	97.07	40.02	31.06	99.73	100.17	44.21
T ₄ : 100% RDF + VAM	24.65	86.08	93.35	37.79	29.54	92.75	93.40	40.07
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	31.62	106.45	108.03	45.64	37.18	114.13	112.90	49.88
T ₆ : 75% RDF + VAM	18.05	69.24	70.46	25.83	21.90	73.29	72.73	29.09
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	28.72	99.70	100.01	42.72	33.87	104.86	102.93	45.95
SEm (\pm)	1.87	6.62	5.54	2.56	2.52	7.05	7.19	3.20
CD (P=0.05)	6.98	20.40	17.08	7.89	7.75	21.73	22.15	9.85
CV (%)	14.09	13.82	11.23	13.09	13.61	13.76	14.17	14.79

Table 8. Effect of different levels of fertilizers in combination with biofertilizers on zinc uptake (g ha^{-1}) at different growth stages of maize

Treatments	Kharif (2020)				Kharif (2021)			
	Knee high	Tasseling	Harvest		Knee high	Tasseling	Harvest	
			Straw	Grain			Straw	Grain
T ₁ : Control	29.03	124.23	129.39	82.32	32.43	131.91	132.71	90.23
T ₂ : 100% RDF	48.59	211.57	222.32	149.27	55.14	228.67	227.93	157.98
T ₃ : 125% RDF	63.00	238.04	261.70	181.17	72.16	250.23	268.21	181.51
T ₄ : 100% RDF + VAM	60.53	228.78	246.16	173.77	67.54	242.50	251.15	176.78
T ₅ : 100% RDF + VAM+ <i>Azospirillum</i> + PSB	74.99	266.58	290.77	201.37	83.73	286.71	301.62	209.66
T ₆ : 75% RDF + VAM	44.36	184.97	199.27	128.40	50.51	194.37	204.79	133.00
T ₇ : 75% RDF + VAM + <i>Azospirillum</i> + PSB	68.22	253.45	269.77	195.87	77.16	269.16	277.49	195.72
SEm (\pm)	4.81	12.66	15.22	9.10	5.33	14.45	18.49	11.17
CD (P=0.05)	14.82	39.00	46.89	28.03	16.41	44.54	56.98	34.43
CV (%)	14.93	10.18	11.39	9.80	14.65	10.93	13.48	11.76

3.2.4 Zinc uptake

Among the different treatments applied, the treatment T₅ that received 100% RDF +VAM + *Azospirillum* and PSB (74.99, 266.58, 290.77, 201.37 g ha⁻¹ in 2020 and 83.73, 286.71, 301.62, 209.66 g ha⁻¹ in 2021) was at par with the treatments T₇, T₃ and T₄ at knee high, tasseling and harvest (straw and grain) stages of maize during the 2020 and 2021, respectively. The recommended dose of fertilizer T₂ (100% RDF) (48.59, 211.57, 222.32, 149.27 g ha⁻¹ in 2020 and 55.14, 228.67, 227.93, 157.98 g ha⁻¹ in 2021) was on par with T₃, T₄, T₆ and T₇ at knee high, tasseling and harvest (straw + grain) stages of maize crop, respectively. The lowest zinc uptake was recorded with the treatment T₁ (29.03, 124.23, 129.39, 82.32 g ha⁻¹ in 2020 and 32.43, 131.91, 132.71, 90.23 g ha⁻¹ in 2021) (Table 8). Increased cationic micronutrient uptake at higher level of fertilizers and biofertilizers could be due to the reason that release of NH₄⁺ and K⁺ into soil solution in higher quantities may release cations including micronutrients from soil exchange complex and help in root exchange and thus might increase their availability, concentration and uptake. Increased accumulation of nutrients especially nitrogen, phosphorus, potash and zinc in vegetative parts might be due to improved metabolism and led to greater translocation of these nutrients to reproductive structures of the crop. The increased photosynthetic efficiency, which favoured dry matter production and nutrient concentration in plants, seems to be the major factor responsible for higher nutrient uptake. These results are in close conformity with Kumar et al. [17,18].

4. CONCLUSION

The combined application of biofertilizers and inorganic fertilizers significantly increased nutrient content and uptake at different growth stages of maize crop. The split application of inorganic fertilizers increased plant nutrient content and uptake of maize. The additional effect of improvement in plant nutrition status might be due to biofertilizers and inorganic dose which in combination gave better result in integrated treatments. The increased nutrient uptake could be due to higher dry matter accumulation at different stages of crop growth as uptake being the product of nutrient content and dry matter accumulation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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