International Journal of Research in Agronomy 2024; 7(12): 237-243

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

www.agronomyjournals.com
2024; 7(12): 237-243
Received: 12-10-2024
Accepted: 15-11-2024

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Influence of microbial culture and their consortia on concentration and uptake of nutrients in Turmeric

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i12c.2142

Abstract
The present field experiments was undertaken at vegetable research Center, Vasantrao Naik Marathwada Agriculture university, Parbhani, Maharashtra, India during the *Kharif* seasons of 2022 and 2023 to study the influence of microbial culture and their consortia on concentration and uptake of nutrients in Turmeric. Ten different treatments combinations were used in the experiments which included different microbial culture and their consortia. The result emerged from field experiments significantly highest the plant and rhizomes nutrients content was reported in treatment T_{10} i.e. RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) followed by T_8 i.e. RDF + *Azotophos* + KSB inoculation (Consortium-V). The significantly highest plant and rhizome Nitrogen, phosphorus and potassium uptake was reported in treatment T_{10} i.e. RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) followed by T_9 i.e. RDF + *Azotophos* + SSB inoculation (Consortium-VI). The plant and rhizome Zn, Fe, Mn and Cu uptake was significantly highest in treatment T_{10} i.e. RDF + *Azotophos* + ZnSB inoculation (Consortium-VII). Study concludes that recommended dose of fertilizers with microbial consortia helped in improving yield and quality of turmeric grown in Vertisol.

Keywords: Microbial consortia, turmeric, nutrient content, nutrient uptake

Introduction

Turmeric (*Curcuma longa* L.) is known as the "golden spice" as well as the "spice of life". It is an ancient, most valuable and sacred spice of India which belongs to the family of *Zingiberaceae*. It is the dried underground rhizome of perennial herb *Curcuma longa* L., which comes from Arabic name for the plant, *Kurkum*. Turmeric is a plant distributed throughout tropical and subtropical regions of the world. It is widely cultivated in Asian countries, mainly in China and India. The native of turmeric is South East Asia particularly India (Angles *et al*., 2011) [3].

Turmeric is a long duration (8-9 months) being an exhaustive crop responds well to nutrition. Hence, optimum dose of nutrients is essential to get good yield. Application of organic manures has been the traditional means of maintaining soil fertility, ecological balance and in recent years there is a great demand for the organically produced turmeric worldwide especially in European countries. The adverse effects of continuous use of high dose of chemical fertilizers on soil health and environment are being realized. Hence, the farmers are also showing considerable inclination towards traditional farming with least usage of chemical fertilizers. The role of organic manures in improving soil structure and fertility is well understood. Organic manures have positive influence on soil texture, structure, water holding capacity and drainage which in turn help for better growth and development of rhizomatous crop like turmeric (Kale *et al*., 1991) [8]. Different organic manures influence differently in terms of yield and quality of turmeric. Hence, it is necessary to know the best source of organic manure which could help in increasing the yield and quality.

Microbial consortium has emerged as a promising approach for sustainable agriculture. A microbial consortium comprises a community of microorganisms, including bacteria, fungi and other microorganisms that work collaboratively to provide essential functions to the ecosystem. Each component of the microbial consortium plays a specific role in the ecosystem, and their interaction with each other and the environment is crucial to their function.

For example, bacteria possess desirable properties that promote plant growth, such as nitrogen fixation, production of *phytohormones*, *siderophore*, EPS and nutrient solubilization (zinc, phosphorus, and potassium). Fungi, particularly mycorrhizal fungi, play a critical role in enhancing nutrient supply to plants. Moreover, certain microbial species can be employed as effective bio pesticide agents, demonstrating significant potential in pest control strategies. Such promising results have spurred increasing interest in the use of microbial consortia in agriculture. Involving the microbial consortium in agriculture has shown significant potential for improving soil health. The use of a microbial consortium has shown its effectiveness in improving soil structure, water holding capacity and nutrient availability essential for plant growth. Bio formulation based on microbial consortia can also suppress soil-borne pathogens and reduce the incidence of diseases in plants. This is because the microbial consortium can outcompete the pathogenic microorganisms, preventing them from establishing in the soil (Upadhayay *et al*., 2023) [21].

In order to achieve sustainable agriculture, biofertilizers are becoming more and more important as a viable substitute for dangerous chemical fertilizers. In order to preserve long-term soil fertility and increase crop output, which is crucial for supplying the world's growing food demand, biofertilizers are used. Crop plants can interact with microbes to improve their defenses, development, and growth. The needed nutrients for optimum crop growth include nitrogen, phosphorous, potassium, zinc, and silica; nevertheless, these nutrients are normally present in complex or insoluble forms. They become soluble and accessible to the plants thanks to certain bacteria. In this overview, the prospective microorganisms, their mode of operation, and their impact on crops are reviewed. Biofertilizers are a fantastic alternative to pricey and damaging chemical fertilisers since they are affordable, non-toxic and environmentally benign. We can better grasp the value of microorganisms in agriculture and how to use them as biofertilizers for sustainable crop development using the knowledge we have gathered from this review (Nosheen *et al*., 2021) [12].

Application of liquid bio-fertilizers inoculation in crops has been of much significance as *Azotobacter* and *Azospirillium* for atmospheric nitrogen, also known for synthesis of biologically growth promoting substances whereas, PSB are important microbes in releasing and making available phosphorus by colonizing the root surface of growing plant root. They also improve the plant growth due to increase in nutrient uptake particularly phosphorus, zinc and other micro-nutrients, production of growth promoting substances and resistance to plant pathogen. These bio-fertilizers are organic in origin and thus, are absolutely safe. Therefore, it is essential to adopt a strategy of integrated nutrient management using combination of chemical fertilizers, organic manures and biofertilizers, so as to minimize the cost of production and to maintain biological productivity of soil, particularly because the farmers are reluctant to adopt recommended fertilizer doses due to the high cost and risk of crop failures on account of aberrant weather conditions.

Materials and Methods

Field Experiment

The experiments on turmeric were conducted to study the "Influence of microbial culture and their consortia on concentration and uptake of nutrients in Turmeric". Field experiments on turmeric were conducted at the same site in two successive years during *Kharif* 2022-23 and *Kharif* 2023-24 at Vegetable Research centre, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The experiment was laid out in randomized block design with three replications and ten treatments. Ten different treatments combinations were used in the experiments which included different microbial culture and their consortia. Rhizome inoculation was done with Different microbial culture and their consortia as rhizome treatment before sowing. The variety used was SALEM. The recommended dose of chemical fertilizers was applied @ 200:100:100 N and P_2O_5 and K_2O kg ha^{-1} through urea, SSP and MOP. A basal dose of phosphorus and potassium fertilizer and 2 Split dose of nitrogen was applied as per treatment at the time of sowing to turmeric. Irrigation was given as per crop need. The recommended package of practices was followed. The rhizome and straw yields were recorded from net plot area at maturity stage of the crop.

Statistical Analysis

The data obtained from the field experiment was done by completely randomized design as per the methods described in "Statistical Methods for Agricultural Workers" by Panse and Sukhatme (1985) [13]. The appropriate standard error (S.E.) and critical differences (C.D.) at 5% level were worked out as and when necessary and used for data interpretation.

Results and Discussion

The results show that different microbial culture and their consortia significantly influences Nutrients content and uptake in Turmeric

Macro nutrient content (NPK)

Nitrogen concentration of Turmeric rhizome and straw

The different microbial culture and their consortium with fertilizers showed significant effect on nitrogen content of rhizomes and straw of turmeric presented in Table 1. Microbial treatments influenced on nitrogen content which was ranged between 1.36-1.78% and 1.04-1.26% of rhizomes and straw of turmeric respectively. The nitrogen concentration of turmeric rhizomes significantly and positively influenced by coinoculation of different microbial cultures and their consortium in turmeric. The highest N concentration in rhizome was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (1.78 per cent) which was followed by T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (1.73 per cent), T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (1.72 per cent) and T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (1.70 per cent). Lowest N concentration in straw and rhizome was noticed in treatment T1 Absolute Control. The co-inoculation of different microbial cultures and their consortium with RDF enhanced the N-fixation in all the treatments as compared to T_1 Absolute Control.

Phosphorus concentration of Turmeric rhizome and straw

It was evidence from data presented in Table 1. That phosphorus content of turmeric rhizome and straw was positively and significantly influenced by microbial consortium with recommended dose of fertilizers. The P concentration of turmeric rhizome significantly influenced by inoculation of different microbial cultures and their consortium with RDF in turmeric. The highest P concentration at rhizome was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (0.65 per cent) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (0.62 per cent), T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (0.60 per cent) and treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (0.55 per cent). The P concentration of turmeric straw in calculated two year data significantly and positively influenced by inoculation of different microbial cultures and their consortium along with RDF. The highest P concentration in two year data was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (0.46 per cent) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (0.40 per cent) and treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (0.37 per cent). Lowest P concentration in straw and rhizome was noticed in treatment T1 Absolute Control.

Potassium concentration of Turmeric rhizome and straw

The different microbial culture and their consortium on potassium content which was ranged between 1.50-2.08% and 1.03-1.32% of rhizomes and straw of turmeric respectively (Table 1). The potassium concentration of turmeric rhizome significantly influenced by inoculation of different microbial cultures and their consortium with RDF in turmeric. The highest P concentration at rhizome was noticed in treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (2.11 per cent) which was at par with treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (2.08 per cent) and treatment T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (1.98 per cent). The K concentration of turmeric straw in calculated pooled data significantly and positively influenced by inoculation of different microbial cultures and their consortium along with RDF. The highest K concentration in pooled was noticed in treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (1.38 per cent) which was at par with treatment T_5 RDF + *Azotobacter* + KSB inoculation (Consortium-II) (1.37 per cent), T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (1.32 per cent) and treatment T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (1.31 per cent). Lowest K concentration in straw and rhizome was noticed in treatment T1 Absolute Control.

Micronutrient content (Fe and Zn)

Zinc concentration of Turmeric rhizome and straw

The different microbial culture and their consortium influenced on zinc concentration which was ranged between 31.02-44.40 and 24.54-36.45 mg kg^{-1} of rhizomes and straw of turmeric respectively. Zn concentration of turmeric rhizome significantly influenced by inoculation of different microbial cultures and their consortium with RDF in Turmeric. The highest Zn concentration at rhizome was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (44.4 mg kg^{-1}) which was followed by treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (41.1 mg kg^{-1}) and T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI)) (40.7 mg kg^{-1}). The Zn concentration of turmeric straw in calculated pooled data significantly and positively influenced by inoculation of different microbial cultures and their consortium along with RDF. The highest Zn concentration in pooled was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (36.45 mg kg^{-1}) which was at par with treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (34.40 mg kg^{-1}), T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (34.06 mg kg^{-1}) and treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (32.99 mg kg^{-1}). Lowest Zn concentration in straw and rhizome was noticed in treatment T_1 Absolute Control.

Iron concentration of Turmeric rhizome and straw

The different microbial culture and their consortium influence on iron concentration and ranged between 125.10-166.44 and 25.81-43.54 mg kg^{-1} for rhizomes and straw respectively. Fe concentration of turmeric rhizome significantly influenced by inoculation of different microbial cultures and their consortium with RDF in Turmeric The highest Fe concentration at rhizome was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (166.4 mg kg^{-1}) which was at par with treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (164.6 mg kg^{-1}) and treatment T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (157.9 mg kg^{-1}). The Fe concentration of turmeric straw in calculated pooled data significantly and positively influenced by inoculation of different microbial cultures and their consortium along with RDF. The highest Fe concentration in pooled was noticed in treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (43.5 mg kg^{-1}) which was at par with treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (41.1 mg kg^{-1}). Lowest Fe concentration in straw and rhizome was noticed in treatment T_1 Absolute Control.

Table 1: Effect of different microbial culture and their consortium on Nitrogen, phosphorus and potassium content in turmeric

Treatments	Nitrogen content (%)		Phosphorus Content (%)		Potassium Content (%)	
	Rhizome	Straw	Rhizome	Straw	Rhizome	Straw
Absolute Control	1.36	1.04	0.34	0.22	1.50	1.03
RPP (Recommended Package of Practices)	1.54	1.10	0.41	0.30	1.73	1.12
T_2 + *Azotobacter* inoculation	1.60	1.12	0.42	0.32	1.75	1.15
T_2 + *Azotophos* inoculation (Consortium-I)	1.62	1.15	0.52	0.35	1.77	1.17
T_2 + *Azotobacter* + KSB inoculation (Consortium-II)	1.64	1.15	0.50	0.33	1.89	1.37
T_2 + *Azotobacter* + SSB inoculation (Consortium-III)	1.65	1.14	0.50	0.36	1.81	1.21
T_2 + *Azotobacter* + ZnSB inoculation (Consortium-IV)	1.70	1.17	0.55	0.35	1.82	1.24
T_2 + *Azotophos* + KSB inoculation (Consortium-V)	1.73	1.20	0.62	0.40	2.11	1.38
T_2 + *Azotophos* + SSB inoculation (Consortium-VI)	1.72	1.19	0.60	0.37	1.98	1.31
T_2 + *Azotophos* + ZnSB inoculation (Consortium-VII)	1.78	1.26	0.65	0.46	2.08	1.32
SEM±	0.03	0.02	0.03	0.03	0.04	0.04
CD at 5%	0.11	0.07	0.11	0.09	0.12	0.14

Table 2: Effect of different microbial culture and their consortium on Zinc and iron content in turmeric

Treatments	Zinc Content (Mg Kg^{-1})		Iron Content (Mg Kg^{-1})	
	Rhizome	Straw	Rhizome	Straw
Absolute Control	31.2	24.54	125.1	25.8
RPP (Recommended Package of Practices)	33.7	27.91	132.9	27.9
T_2 + *Azotobacter* inoculation	37.2	30.58	143.6	31.4
T_2 + *Azotophos* inoculation (Consortium-I)	37.9	31.21	145.3	33.1
T_2 + *Azotobacter* + KSB inoculation (Consortium-II)	36.5	29.85	149.7	36.2
T_2 + *Azotobacter* + SSB inoculation (Consortium-III)	38.0	31.31	147.7	35.0
T_2 + *Azotobacter* + ZnSB inoculation (Consortium-IV)	41.1	34.40	164.6	41.1
T_2 + *Azotophos* + KSB inoculation (Consortium-V)	39.7	32.99	152.3	38.1
T_2 + *Azotophos* + SSB inoculation (Consortium-VI)	40.7	34.06	157.9	39.2
T_2 + *Azotophos* + ZnSB inoculation (Consortium-VII)	44.4	36.45	166.4	43.5
SEM±	1.08	1.32	3.81	1.37
CD at 5%	3.21	3.92	11.34	4.09

Macro nutrient uptake (NPK)

Nitrogen uptake of Turmeric rhizome and straw

Microbial treatments influenced on nitrogen uptake of rhizomes and straw which was ranged between 43.47-104.19 and 16.59-30.43 kg ha^{-1} respectively. For total nitrogen uptake of turmeric influenced by microbial inoculation and ranged between 60.06-133.70 kg ha^{-1}. The rhizome nitrogen uptake was found higher in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (104.19 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (97.05 kg ha^{-1}) and treatment T_7 RDF + *Azotobacter* + ZnSB inoculation (Consortium-IV) (95.61 kg ha^{-1}). The higher straw nitrogen uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (30.43 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (28.26 kg ha^{-1}). The higher total nitrogen uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (133.70 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (124.97 kg ha^{-1}). Lowest straw, grain and total Nitrogen uptake was noticed in treatment T1 *i.e.* Absolute Control.

Phosphorus uptake of rhizome and straw

The microbial consortium influenced on phosphorus uptake and ranged between 10.60-37.84, 3.48-11.27 and 14.15-49.12 kg ha^{-1} for rhizomes, straw and total respectively. The rhizome P uptake was found higher in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium VII) (37.81 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (34.03 kg ha^{-1}) and treatment T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (33.08 kg ha^{-1}). The higher straw P uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (11.27 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (9.33 kg ha^{-1}). The higher total P uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (49.12 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (43.97 kg ha^{-1}). Lowest rhizome, straw and total P uptake was noticed in treatment T1 *i.e.* Absolute Control.

Potassium uptake of Turmeric rhizome and straw

Microbial treatments influenced on potassium uptake of rhizome and straw which was ranged between 47.40-121.44 and 15.91-32.42 kg ha^{-1} respectively. For total potassium uptake of turmeric influenced by microbial inoculation and ranged between 63.31-153.86 kg ha^{-1}. The higher K uptake of rhizome was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (121.44 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (116.90 kg ha^{-1}). Higher K uptake of straw was noticed in application of treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (32.54 kg ha^{-1}) which was at par with treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (32.42 kg ha^{-1}), T_9 RDF + *Azotophos* + SSB inoculation (Consortium-VI) (28.39 kg ha^{-1}) and treatment T_5 RDF + *Azotobacter* + KSB inoculation (Consortium-II) (28.38 kg ha^{-1}). While higher total K uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (153.86 kg ha^{-1}) which was at par with treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (149.44 kg ha^{-1}). Lowest straw, grain and total K uptake was noticed in treatment T1 *i.e.* Absolute Control.

Micronutrient uptake (Fe and Zn)

Zinc uptake of Turmeric rhizome and straw

The data narrated in Table 4 regarding zinc uptake is given. Zinc uptake of rhizome and straw estimated separately and total zinc uptake was also calculated. Microbial treatments influenced on zinc uptake of rhizome and straw which was ranged between 98.20-258.81 and 38.10-90.58 g ha^{-1} respectively. The Zinc uptake of turmeric rhizome varies from 98.2 to 258.8 g ha^{-1}. Higher Zn uptake of rhizome was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (258.8 g ha^{-1}). Higher Zn uptake of straw was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (90.58 g ha^{-1}) which was followed by treatment T_8 RDF + *Azotophos* + KSB inoculation (Consortium-V) (77.78 g ha^{-1}). While, higher total Zn uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (349.3 g ha^{-1}). Lowest rhizome, straw and total Zn uptake was noticed in treatment T_1 *i.e.* Absolute Control.

Iron uptake of Turmeric straw and Rhizome

The data narrated in Table 3 about iron uptake is given. Iron uptake of rhizome and straw estimated separately and total iron uptake was calculated. The microbial inoculants influence on iron uptake and ranged between 394.9-967.6, 39.31-106.60 g ha^{-1} for rhizome, straw and 434.22- 1074.35 g ha^{-1} for total respectively. Higher Fe uptake of rhizome, straw and total uptake was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (967.6, g ha^{-1})

Lowest rhizome, straw and total Fe uptake was noticed in treatment T_1 *i.e.* Absolute Control. Higher Fe uptake of straw was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (106. g ha^{-1}) Lowest rhizome, straw and total Fe uptake was noticed in treatment T_1 *i.e.* Absolute Control. While, higher Fe uptake of straw was noticed in application of treatment T_{10} RDF + *Azotophos* + ZnSB inoculation (Consortium-VII) (1074.35 g ha^{-1}) Lowest rhizome, straw and total Fe uptake was noticed in treatment T_1 *i.e.* Absolute Control.

Table 3: Effect of different microbial culture and their consortium on nitrogen, phosphorus and potassium uptake in turmeric

Treatments	Nitrogen uptake (kg ha^{-1})			Phosphorus Uptake (Kg Ha^{-1})			Potassium Uptake (Kg Ha^{-1})		
	Rhizome	Straw	Total	Rhizome	Straw	Total	Rhizome	Straw	Total
Absolute Control	43.47	16.59	60.06	10.66	3.48	14.15	47.40	15.91	63.31
RPP (Recommended Package of Practices)	66.25	19.28	86.17	17.16	5.26	22.42	72.52	19.26	91.78
T_2 + *Azotobacter* inoculation	77.49	20.89	98.38	19.91	5.85	25.76	83.01	21.33	104.34
T_2 + *Azotophos* inoculation (Consortium-I)	85.10	24.77	109.88	27.24	7.69	34.93	91.53	25.04	116.57
T_2 + *Azotobacter* + KSB inoculation (Consortium-II)	86.79	24.13	112.30	25.49	6.72	32.22	96.45	28.38	124.83
T_2 + *Azotobacter* + SSB inoculation (Consortium-III)	83.44	22.44	105.88	25.03	7.01	32.04	90.54	23.52	114.06
T_2 + *Azotobacter* + ZnSB inoculation (Consortium-IV)	90.44	23.30	113.74	28.42	6.92	35.35	95.02	24.69	119.71
T_2 + *Azotophos* + KSB inoculation (Consortium-V)	97.05	28.26	124.97	34.63	9.33	43.97	116.90	32.54	149.44
T_2 + *Azotophos* + SSB inoculation (Consortium-VI)	95.61	25.49	120.73	33.08	8.03	41.11	109.32	28.39	137.71
T_2 + *Azotophos* + ZnSB inoculation (Consortium-VII)	104.19	30.43	133.70	37.84	11.27	49.12	121.44	32.42	153.86
SEM±	3.39	1.49	3.51	2.05	0.89	1.89	3.10	1.83	3.31
CD at 5%	10.08	4.43	10.45	6.11	2.65	5.62	9.21	5.44	9.84

Table 4: Effect of different microbial culture and their consortium on zinc and iron uptake in turmeric

Treatments	Zinc Uptake (G Ha^{-1})			Iron Uptake (G Ha^{-1})		
	Rhizome	Straw	Total	Rhizome	Straw	Total
Absolute Control	98.2	38.10	136.3	394.9	39.3	434.2
RPP (Recommended Package of Practices)	141.8	48.76	190.5	559.5	47.7	607.2
T_2 + *Azotobacter* inoculation	177.0	56.64	233.6	682.1	57.5	739.6
T_2 + *Azotophos* inoculation (Consortium -I)	196.9	66.81	263.7	753.8	70.5	824.3
T_2 + *Azotobacter* + KSB inoculation (Consortium -II)	185.6	62.08	247.7	762.7	74.2	836.9
T_2 + *Azotobacter* + SSB inoculation (Consortium -III)	190.7	61.03	251.8	741.0	67.5	808.5
T_2 + *Azotobacter* + ZnSB inoculation (Consortium -IV)	216.6	68.03	284.6	863.3	81.2	944.5
T_2 + *Azotophos* + KSB inoculation (Consortium -V)	220.3	77.78	298.1	844.2	88.9	933.1
T_2 + *Azotophos* + SSB inoculation (Consortium -VI)	224.5	73.53	298.0	872.8	84.4	957.2
T_2 + *Azotophos* + ZnSB inoculation (Consortium -VII)	258.8	90.58	349.3	967.6	106.6	1074.3
SEM±	9.68	4.88	11.49	31.68	4.65	32.60
CD at 5%	28.78	14.51	34.13	94.15	13.83	96.86

Discussion

Increase in the nutrient concentration in the plants showed to more bioavailability of nutrients in the root zone. Microbial releases different organic acids which solubilize the nutrients in soil and enhanced the nutrient concentration in soil and hence more uptake by plants takes place. As per earlier reports, co-inoculation enhanced the N, P, K levels in soil due to increase in root hair density, more lateral roots, root surface area thus more nitrogen fixation and phosphate solubilization taking place. Phytohormone producing microbes enhanced the root mass and length thus enhanced the nutrient concentration in plants (Qureshi *et al*. 2011) [16]. Han and Lee (2006) [6] reported that inoculation phosphate solubilizing bacteria (PSB) *i.e. Bacillus megaterium var. phosphaticum* and potassium solubilizing bacteria (KSB) *i.e. Bacillus mucilaginosus* significantly and positively effects on absorption of N, P, and K by shoot and root, and the development of pepper and cucumber were all boosted by the integration of rock P with PSB inoculation. Combining the two bacterial strains and the rock materials consistently boosted the availability of minerals, their absorption, and the development of the pepper and cucumber plants, indicating a possible application for the mixture as fertilizer. Vessey (2003) [22] reported that the potential improvement in K and P nutrition by application of PGPR including phosphate and potash solubilizing bacteria (PSB and KSB) as biofertilizers. He stated that the plant nutrient status and production also enhanced by this microbial inoculation. The increase in phosphorus content in turmeric is might be due to increased phosphorous availability in soil due to solubilization effect of different microbial isolates. Increased nutrient bioavailability in the root zone was demonstrated by the plants' higher nutrient content. Plant absorption increased as a result of increased soil nitrogen concentration brought on by microbial nutrient release. Previous research indicates that co-inoculation raised the amounts of N and P in the soil because nodulation, larger root surface area, and lateral roots led to higher levels of nitrogen fixation and phosphate solubilization. Similarly, Han and Lee (2006) [6], Sharma *et al*. (2013) [19] and Singh *et al*. (2016) [20] stated that seed inoculation with biofertilizer had a substantial impact on the nutrients content of black gram. Over the other treatments, the *Rhizobium* + PSB treatment had the highest nutrients content in shoot and leaves. Kumar *et al.* (2016) [10] reported that Zn solubilizing microbial cultures enhanced the yield, nutrients content, nutrient uptake and quality of soybean and was increased with the application of microbial culture *i.e.* RDF + *Rhizobium* + *Trichoderma viride*. The increase in zinc content of straw and rhizome is might be due to increased zinc availability in soil due to solubilization effect of *Pseudomonas striata*, *Bacillus megaterium*, *Trichoderma viride* and other different microbial cultures and their consortium *in vitro* condition. The increased nutrient concentration might be due to greater availability of nutrient through inorganic, organic and biological sources by enhancing the activity of root hair, root proliferation and cell development in the root surface area.

The increased content was also due to added supply of nutrients and well-developed root system under balanced nutrient application resulting in better absorption of nutrients. Kumar *et al.* (2016) [10] stated that Zn solubilizing microbial isolates enhanced yield, nutrients content, nutrient uptake and quality of soybean and reported that nutrient concentration and uptake of soybean increased with the application of microbial culture *i.e.* RDF + *Rhizobium* + *Trichoderma viride*. Haroon *et al.* (2022) [7] showed that Zn biofortification of crops using these heterotrophic organisms such as strains of *Gluconacetobacter sp., Acinetobacter sp., Burkholderia sp., Klebsiella sp., Ralstonia sp., Bacillus sp., Pseudomonas sp., Serratia sp.* and *Ericoid mycorrhizal* boost the uptake of Zn by plants. Saravanan *et al*. (2007) [18] the ability to dissolve immobilized zinc *viz*. zinc phosphate, zinc oxide and zinc carbonate in appreciable quantity is not common feature amongst the cultivable bacteria on soil surface. Few Zn solubilizing bacterial genera *viz. Thiobacillus thiooxidans, Thiobacillus ferroxidans, Acinetobacter, Bacillus, Gluconacetobacter, Pseudomonas* and facultative thermophilic iron oxidizers have been reported as zinc solubilizers. The enhancement of macro and micro nutrient content and uptake by plants by inoculation with different microbial cultures and their consortium may be due to their effect on initiation and development of lateral roots increased root weight and nutrient uptake also increased in iron content of leaves and grain was might be due to increased iron availability in soil due to siderophore producing ability of *Pseudomonas striata, Bacillus megaterium, Bacillus subtilis, Trichoderma viride* and other plant growth promoting microorganisms *in vitro* condition. Our findings have been similar with Sharma *et al*. (2013) [19] they reported that PGPRs includes *Pseudomonas putida, Pseudomonas fluorescens* and *Azospirillum lipoferum*, which were isolated from rhizospheric soils and application on rice plants as a seed treatment. They found that in iron content in plants and grain virtually increased after inoculation. In addition, after treatment, the iron ability to move from roots to shoots to grains was improved. Similarly, Gamit and Tank (2014) [5] showed that siderophore producing *Pseudomonas pseudoalcaligenes* promote the solubility of nutrients such as Fe and increase the uptake of Fe in *Cajanas cajan*. Kumar *et al.* (2016) [10] showed that coinoculation of *Rhizobium* and *Trichoderma viride* along with RDF enhanced the yield, nutrients content, nutrient uptake and quality of soybean crop.

Han and Lee (2006) [6] showed that co-inoculation of phosphate solubilizing bacteria (PSB) *Bacillus megaterium var. phosphaticum* and potassium solubilizing bacteria (KSB) *Bacillus mucilaginosus* consistently increased P and K availability in soil than in the control without bacterial inoculums. The absorption and uptake of N, P and K by shoot and root, and the development of pepper and cucumber were all boosted by the integration of rock P with PSB inoculation. Consistently boosted the availability of minerals, their absorption, and the development of the pepper and cucumber plants. Alagaadi and Gaur (1988) reported that inoculation of Rhizobium, *P. striata or B. polymyxa* significantly increased the N and P uptake by chickpea over control. The uptake was further enhanced with the application of 10kg N and 60 kg P2O5 ha^{-1}. The highest N and P uptake was recorded in Rhizobium + 60 kg N and 60 kg P_2O_5 ha^{-1}. Dong Thap (2007) [4] observed that the N uptake was increased from 12.12 to 17.82% and P increased from 12.10 to 13.71% under application of *Bradyrhizobial* and PSB as compared to farmer's fertilizer level (un- inoculant). Kumar *et al*. (2010) [11] studied the effect of combined application of *Rhizobium* + PSM and found more N and P uptake. The magnitude of increase in N uptake was 72.8, 33.7 and 39.6% in seed and 66.3, 25.1 and 33.2% in straw, whereas P uptake was 83.1, 36.8 and 29.1% in seed and 59.1, 22.2 and 17.9% in straw by green gram respectively over the *Rhizobium* and PSB alone. The uptake of N and P might have increased due to increased content and biological yield with the use of biofertilizers. Increase in Fe uptake might be due to siderophores produced by rhizosphere microorganisms are iron chelating ligands which can be beneficial to plants can supply iron to plants under iron stress or iron limiting conditions by increasing the solubility of ferric iron (Fe III), which otherwise is unavailable for plant nutrition. This element is assimilated by root cells in the reduced form (Fe II) however, especially in sufficiently aerated soils, the oxidized state (Fe III) is predominant and needs to be reduced to be taken up by plants. Plant roots have receptors or channels which can receive microbial siderophore, and plant ferric reductase helps in unloading of iron and converting it to the ferrous form (Altomare *et al*. 1999) [2]. Moreover, supply of additional iron through fertilizers also play important role in increasing more uptake by wheat crop. The research of this investigation are in consonance with the findings of reported the content and uptake of Fe, Zn, Mn and Cu by groundnut was also found to be significantly highest with the inoculation of RDF + Rhizobium + Pseudomonas striata. Kiran *et al*. (2017) [9] reported highest increase in Fe uptake (4850 g ha1) in treatment T_7 (GRDF + 20 kg ZnSO4 ha^{-1} + 25 kg FeSO4 ha^{-1} + seed inoculation of Fe and Zn solubilizers) over other treatments in wheat crop. Similarly, Parmer *et al*. (2020) reported higher uptake of Fe noted with 25 kg ha-1 ZnSO4 + 50 kg ha-1 FeSO4.The treatment RDF+ 25 kg ha-1FeSO4 + 25 kg ha^{-1} ZnSO4 recorded the significantly highest iron uptake reported by Waikar *et al*. (2021) [23] noted that highest iron uptake in treatment RDF + 25 kg ha-1 FeSO4 +25 kg ha^{-1} FeSO4 and lowest iron uptake was observed in absolute control.

Conclusions

From the results it can be concluded that application of different microbial culture and their consortia along with recommended dose of fertilizers i.e. RDF + *Azotophos* + ZnSB inoculation, RDF + *Azotophos* + KSB inoculation and RDF + *Azotophos* + SSB inoculation significantly increases Nitrogen, phosphorus, potassium and micronutrients (Zn and Fe) content in turmeric. Also, significant increase Nitrogen, phosphorus, potassium and micronutrients (Zn and Fe) uptake in turmeric with application of different microbial culture and their consortia along with recommended dose of fertilizers.

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