Madras Agric. J., 103 (7-9): 207-212, September 2016
https://doi.org/10.29321/MAJ.10.001021

Effect of Graded Levels of Zn and Microbial Inoculation on NPK Availability and their Uptake for Maize in Black Soil

Suganya Ayyar [1*] and Saravanan Appavoo [2]
[1]Department of Soil Science and Agricultural Chemistry, Water Technology Centre,
Tamil Nadu Agricultural University, Coimbatore - 641 003.
[2]Department of Soil Science and Agricultural Chemistry, Soil and Water Management Research Institute,
Kattuthottam, Thanjavur - 613 501.

A Field experiment was conducted during 2014 at Cotton Research Station Farm, Perambalur district in black soil in order to study the soil available NPK and their uptake using *Glomus intraradices* (AM fungus) and zinc solubilizing *Bacillus* sp. (ZSB) in combination with graded levels of $ZnSO_4$ in maize (*Zea mays* L.). Treatments consisted of two factors *viz.,* microbial inoculation (M_1: control, M_2: AM, M_3: ZSB and M_4: AM + ZSB) and graded levels of $ZnSO_4$ (S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} and S_6 @ 0.5% foliar spray on 45 and 65 DAS) replicated thrice in FRBD. The soil available N decreased with the advancement of crop growth in black soil. The combination of AM and ZSB had enhanced the soil available NPK and uptake at vegetative, tasselling and harvest stages of crop growth. Increased doses of $ZnSO_4$ application had positive effect on the soil available N and K at all stages. Graded doses of $ZnSO_4$ on soil available P was not spectacular. Although it enhanced the NPK uptake correspondingly, the increase was not significant beyond 25 kg of ZnSO4 ha^{-1}. Combined application of AM and ZSB along with 50 kg of ZnSO4 ha^{-1} had recorded the highest soil available NPK and their uptake at vegetative, tasselling and harvesting stages. The application of graded doses of $ZnSO_4$ in combination with AM and ZSB had also increased the soil available NPK, which in turn increased the fertility status of soil resulting in increased uptake of all the three primary nutrients.

Key words: Maize, *Glomus intraradices* (AM), Zinc solubilizing *Bacillus* sp., $ZnSO_4$, NPK availability and uptake

In India, maize is grown in a wide range of environment, extending from extreme semiarid to sub humid and humid regions. It is grown in about 9.09 M ha and utilized for versatile purposes. It is one of the main sources of calories and minerals for most of the rural population. In plants nitrogen is considered to be the most important, because it is essential in the formation of protein. Second important nutrient is phosphorus. It is essential for plant growth and cell division. It is also essential in energy transfer and protein metabolism. Complex processes influence the availability of phosphorus applied to the soil. Many soils 'tie up' phosphorus, making it unavailable to plants. Potassium is the third major nutrient after N and P, required by plants for buildup of biomass. It also makes plants tolerant to drought and resistant to a number of diseases and pests, besides influencing yield and quality. K plays a key role in plant water stress and has been found to be the cationic solute, which is responsible for stomatal movement in response to changes in leaf water status, thereby enhancing photosynthesis.

Arbuscular mycorrhizae (AM) are symbiotic associations between plant roots and specialized soil fungi. Occasionally all the AM fungi in any particular soil will colonize all the plants grown there. The symbiosis is based on exchange of nutrients: the fungus increases the ability of host roots to take up nutrients, while the plant provides the fungus with sugars. Importantly, AM fungi grow in the soil as well as inside the roots. Their fine threads (hyphae) extend and branch in soil pores, increasing the amount of soil from which the host plants can extract nutrients. These hyphae also act to spread the symbiosis from plant to plant and stabilize soil structure. Microbes also cater plant nutrient requirements by solubilizing the complex nutrients in soil. A microbe solubilizes the metal forms by protons, chelated ligands, and oxidoreductive systems present on the cell surface and membranes. Soil bacteria also exhibit other traits beneficial to plants, such as production of phytohormones, antibiotics, siderophores, vitamins, antifungal substances and hydrogen cyanide. AM fungi help to increase the availability of nutrient in soils as consequences of rhizospheric acidification and siderosphore production, besides hypal transport of nutrients through the external mycelium (Balakrishnan, 2011). Mycorrhizae are also known to improve the availability of nitrogen particularly, ammoniacal form to plants, which are less mobile in soil. Subramanian and Charest (1999) and Amanullah, (2011) have assessed the hyphal transport of NO_3- N and suggested that 30-35% of added N could be transported by the extra radical mycelium especially, on decomposition of the mycelium, the assimilated N gets disintegrated

*1Corresponding author's e-mail: suganyaayyar@gmail.com

or mineralized, which may contribute for the enhancement of available N content in the soil.

Bacillus sp. can solubilize the complex and unavailable form of nutrient present in the soil through production of organic acid *viz.,* gluconic acid, which is designated as strong acid among mono carboxylic group of acids and is found to be easily biodegradable. Gluconic acid has the major anion, which may be an important agent that helps in the solubilization of insoluble nutrient compounds such as phosphorus and potassium from the native minerals like apatite, mica and feldspar, respectively. The synergistic effect of Zn and N increase the N transformation reaction in soil. With this background, the present study has been contemplated to study the soil available NPK and their uptake by maize grown in black soil.

Materials and Methods

Experimental soil

A field experiment was conducted during 2014 at Cotton Research Station (CRS), Perambalur district situated at 11° 35' North latitude and 78° 80' East longitude at an altitude of 148 m above the MSL. The soil was clay, deep black in color belonged to *Typic Chromustert* (Peelamedu series). The soil was moderately alkaline, non saline, medium in organic status, low, low and medium in available N, P and K, respectively. With regard to the available micronutrient status, DTPA-Fe, DTPA-Cu and DTPA-Mn were found to be in sufficient levels, but the availability of DTPA-Zn was found to be deficient.

Field experiments

Treatments consisted of two factors *viz.,* microbial inoculation (M_1: control, M_2: AM, M_3: ZSB and M_4: M_2+M_3) and graded levels of $ZnSO_4$ (S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} and S_6 @ 0.5% foliar spray on 45 and 65 DAS) replicated thrice in FRBD. Seeds of maize hybrid (NK 6240) were sown on ridges by adopting a spacing of 60 x 25 cm along with the application of vermiculite based mycorrhizal inoculum (*Glomus intraradices* TNAU-03-08) @ 2 g per hill at a depth of 5 cm. Zinc solubilizing *Bacillus* sp. was applied at 2 kg ha^{-1} after mixing it with 25 kg each of sand and farm yard manure. The recommended fertilizer dose for maize *viz.,* 250:75:75 kg of N, P_2O_5 and K_2O ha^{-1} was followed. The full dose of P and K were applied basally and N was applied at three splits *viz.,* basal (25%), vegetative (50%) and tasselling (25%) stages. Calculated quantities of $ZnSO_4$ were applied basally as per the treatment schedule.

Data collection and analysis

Composite surface (0-15 cm) soil samples were collected from the site before the experiment and analyzed for their physical, physio-chemical and chemical properties. Soil samples were also collected from each of the plots at vegetative (30th DAS), tasselling (60th DAS) and harvesting stage of crop for analyse. The samples were air – dried and passed through 2 mm sieve prior to analysis. The pH and EC were determined in 1:2.5 (soil: water) suspension using digital pH meter. Organic carbon (OC) content of soil was determined by chromic acid wet oxidation method (Walkley and Black, 1934); available nitrogen content in soil was determined by alkaline permanganate method (Subbiah and Asija,1956); available phosphorus content in soil was estimated using Olsen's extraction method (Olsen *et al.,* 1945); available potassium in soil was analyzed neutral normal ammonium acetate method as outlined by Jackson (1973); exchangeable calcium and magnesium in soil was determined by Versenate titration - neutral normal ammonium acetate extract (Jackson, 1973) and available micronutrient (Zn, Cu, Fe and Mn) in soil was estimated by Atomic Absorption Spectrophotometer (AAS) after extracting soil samples with DTPA (Diethelene Triamine Penta Acetic Acid) extractant (Linsay and Norvell, 1978).

The plant samples were collected at vegetative, tasselling and harvest stages. After recording the dry weight, the samples were ground to a fine powder in a willey mill. Total N in plant was determined by diacid extract – microkjeldahl distillation (Jackson, 1973); total P in plant was estimated using triacid extract – vanadomolybdate colorimetric method (Jackson, 1973); total K was determined by triacid extract, neutralized with ammonia and estimated using flame photometer (Jackson, 1973).

The data on various characters studied during the investigation were statistically analyzed by the method given by Gomez and Gomez (1984) and the least significant difference (LSD) at 5 % probability level was computed to compare the treatments.

Initial soil characters

Taxonomy	Typic Chromustert
Textural class	Clay
pH (1:2.5 soil : water)	8.34
EC (dS m^{-1})	0.30
Free $CaCO_3$ (g kg^{-1})	90.4
Organic carbon (g kg^{-1})	5.10
CEC (c mol (p$^+$) kg^{-1})	36.2
Alkaline $KMnO_4$- N (kg ha^{-1})	221
Olsen- P (kg ha^{-1})	20.0
Neutral N NH_4Oac- K (kg ha^{-1})	245
DTPA Zn (mg kg^{-1})	0.80
DTPA Cu (mg kg^{-1})	2.52
DTPA Fe (mg kg^{-1})	10.2
DTPA Mn (mg kg^{-1})	3.45

Results and Discussion

Soil available N

Soil available N measured during growth phases was found to be reduced from 285 to 259 kg ha^{-1} from vegetative to harvest stage (Table 1). A marked decline in the soil available N content was observed with the advancement of crop growth, which might be due to the continuous removal of N by the crop and losses due to transformation. The available N content estimated during the vegetative phase showed significant wide variation for the M and S treatments. In vegetative stage, the N content was found to be more for M_4 (299 kg ha[-1]), which was on par with M_3 (292 kg ha[-1]) followed by M_2 (278 kg ha[-1]). The lowest soil available N was which had similar effect as that of control (269 kg ha[-1]). The available N content in black soil was significantly influenced by the application of microbial inoculants and graded levels of $ZnSO_4$.

Table 1. Graded levels of Zn with AM and ZSB on soil available nitrogen (kg ha[-1])

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1 Control	258	265	271	278	283	262	269	250	252	263	270	272	246	259	230	243	249	255	260	239	246
M_2 – AM	265	272	279	290	292	270	278	250	259	264	271	279	251	262	242	250	256	265	271	247	255
M_3 – ZSB	279	290	295	301	306	281	292	261	272	282	294	297	266	278	248	261	266	271	279	258	263
M_4 – M_{2+} M_3	285	293	305	310	312	291	299	271	277	287	296	301	275	285	259	268	277	284	289	263	273
Mean	272	280	287	295	298	276	285	258	265	274	283	287	259	271	245	255	262	269	274	251	259
		SEd			CD (0.05)				SEd			CD (0.05)				SEd			CD (0.05)		
M		5.5			11				5.2			11				5.0			10		
S		6.7			14				6.2			13				6.2			12		
M x S		13.4			28				12.9			26				12.0			NS		

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha $^{-1}$ of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

Mycorrhizae are known to improve the availability of nitrogen, particularly ammoniacal form to plants, which are less mobile in soil. Subramanian and Charest (1999) have assessed the hyphal transport of NO_3-N and suggested that 30-35% of added N could be transported by the extra radical mycelium, especially on decomposition of the mycelium; the assimilated N gets disintegrated or mineralized, which may contribute for the enhancement of available N content in the soil.

With regard to levels of $ZnSO_4$, the treatment S_5 registered higher available N (298 kg ha[-1]) followed by S_4, S_3 and S_2. The available N content in the soil was significantly influenced by the Zn application and might be due to the synergistic effect of Zn and N. The foliar application of $ZnSO_4$ during vegetative phase though had low available N than the soil application treatments, higher available N was recorded when compared to control. The interaction effect of M x S on soil available N at vegetative phase was significant. At all M levels the graded levels of $ZnSO_4$ had increased, the soil available N. The spray treatment of $ZnSO_4$ was on par with control either with or without microbial inoculation in black soil due to no soil interaction. Similar trends of results were obtained during tasselling and harvesting stages also.

Table 2. Graded levels of Zn with AM and ZSB on soil available phosphorus (kg ha[-1])

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1 Control	19.3	18.7	17.4	17.0	16.3	19.4	18.0	19.0	17.1	16.0	15.2	14.8	18.5	16.7	18.0	16.5	15.9	15.0	14.0	17.9	16.2
M_2 – AM	23.1	21.8	19.8	19.0	18.9	22.0	21.3	19.7	19.2	17.9	17.2	16.7	20.1	18.5	18.6	16.9	16.0	15.1	14.6	18.1	16.6
M_3 – ZSB	22.2	20.9	20.8	19.8	19.3	23.0	20.4	21.2	20.1	19.0	18.4	17.8	20.8	19.5	19.0	18.2	16.3	15.7	15.0	19.0	17.2
M_4 – M_{2+} M_3	26.5	24.2	22.1	21.1	20.7	26.2	23.5	22.8	20.9	20.1	19.5	19.2	21.9	20.7	20.1	18.2	17.3	16.3	16.0	19.7	17.9
Mean	22.8	21.58	20.0	19.2	17.8	22.6	20.8	20.7	19.3	18.2	17.6	17.1	20.3	18.9	18.9	17.5	16.4	15.5	14.9	18.7	17.0
		SEd			CD (0.05)				SEd			CD (0.05)				SEd			CD (0.05)		
M		0.55			1.2				0.26			1.0				0.25			0.5		
S		0.69			1.5				0.32			1.2				0.30			0.6		
M x S		0.49			1.0				0.64			NS				0.61			NS		

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha $^{-1}$ of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

Soil available P

The available P content of the black soil during vegetative stage ranged from 19.3 to 26.5 kg ha[-1] (Table 2). It decreased with progressive stages of plant growth. Owing to continuous uptake by the crop and also due to P transformation in soil, the available P content of the soil was found to be decreasing from the vegetative to harvesting stage. The highest available P was noted under M_4 (23.5 kg ha[-1]) followed M_2 (21.3 kg ha[-1]), M_3 (20.4 kg ha[-1]) and M_1 (18.0 kg ha[1]). The graded levels of Zn application had significantly reduced the soil available P. Application of microbial inoculation markedly increased the available P in both the soils (Ananthi, 2010). Among the microbial inoculations, application of AM fungi in combination with ZSB (M_4) had recorded the highest available P (20.1 kg ha^{-1}). The primary effect of mycorrhizal symbiosis is to increase the supply of mineral nutrients to the plant, particularly those whose ionic forms have a poor mobility rate or those which are present in low concentration in the soil solution, especially phosphate. In the present study, it was observed that improved availability of P due to the application of AM fungi in combination with ZSB (M_4). The reason

Table 3. Graded levels of Zn with AM and ZSB on soil available potassium (kg ha^{-1})

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_{1-} Control	211	216	222	229	232	211	220	206	212	219	224	229	206	216	200	207	218	221	225	200	212
M_2 – AM	215	221	232	239	241	216	227	212	218	227	233	238	212	223	203	211	219	222	225	203	214
M_3 – ZSB	215	222	231	240	242	215	228	211	217	227	234	238	211	223	204	212	220	221	225	204	214
M_4 – M_{2+} M_3	218	229	237	248	251	219	234	220	229	237	239	242	220	231	207	217	223	228	231	207	219
Mean	215	222	231	239	242	215	227	212	219	228	233	237	212	223	204	212	220	223	227	204	215
		SEd		CD (0.05)					SEd		CD (0.05)					SEd		CD (0.05)			
M		4.4		9					4.3		9					4.2		7			
S		5.4		11					5.3		11					5.1		11			
M x S		10.7		22					10.5		22					10.2		21			

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

ascribed to this change might be due to acidification of rhizosphere by intense acid phosphatase activity and also Zinc solubilizing bacteria *viz, Bacillus* sp*.* Mycorrhizae inoculated plants were reported to release organic acid that reduce rhizosphere pH and facilitate nutrient availability (Koide and Kabir, 2000). Soil P precipitates as orthophosphate absorbed by Fe and Al oxides is likely to become bio-available by bacteria through their organic acid production and acid phosphatase secretion. The treatments AM fungus (M_2) and AM in combination with ZSB (M_4) influenced the soil available P to a greater extent as compared to control (M_1). Obviously, AM could have acidified and mobilized the insoluble apatite to contribute to the available pool. The enhancement of soil available P at all the stages of observation due to the AM inoculation was much pronounced. Increasing doses of $ZnSO_4$ on soil available P was not spectacular.

Table 4. Graded levels of Zn with AM and ZSB on total nitrogen uptake (kg ha^{-1})

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_{1-} Control	10.1	12.6	16.2	19.1	19.6	11.5	14.9	50	57	76	104	105	46	73	92	109	119	129	127	99	112
M_2 – AM	12.0	14.2	18.5	22.0	23.6	14.0	17.4	52	79	99	116	114	62	87	104	119	131	139	137	107	122
M_3 – ZSB	14.3	18.3	23.1	26.7	29.8	16.8	21.6	61	85	100	118	121	71	93	113	125	137	143	144	111	127
M_4 – M_{2+} M_3	17.9	21.5	28.0	33.3	38.4	21.0	26.7	83	108	130	145	147	94	118	113	130	140	153	155	121	136
Mean	13.6	16.7	21.4	25.3	27.9	15.8	20.1	62	82	101	121	121	68	92	102	121	132	141	141	110	124
		SEd		CD (0.05)					SEd		CD (0.05)					SEd		CD (0.05)			
M		1.30		2.7					4.6		10					1.9		4			
S		1.59		3.3					5.7		12					3.3		7			
M x S		3.18		NS					11.4		NS					7.14		15			

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

There was no much difference in the available P status in the soil among the S_2 (21.58 kg ha^{-1}), S_6 (22.6 kg ha^{-1}) and S_1 (22.8 kg ha^{-1}) but, significantly higher values than S_3 (20.0 kg ha^{-1}), S_4 (19.2 kg ha^{-1}) and S_5 (17.8 kg ha^{-1}) were recorded. The interaction effect of M x S on the soil available P at vegetative stage was significant in black soil. At M_1, significant reduction was observed for the application of $ZnSO_4$ beyond 12.5 kg ha^{-1}. The reduction in available P for the enhanced level of $ZnSO_4$ application treatments S_3, S_4 and S_5 were on par. At all M levels, S_1 and S_6 had similar effect on soil available P. Similar results during tasselling and post harvest stages were recorded. However, the interaction effect on soil available P in black soil was not significant during tasselling and harvest stage.

Soil available K

The available K decreased from vegetative (227 kg ha^{-1}) to post harvest stage (215 kg ha^{-1}) of the crop (Table 3). The available K varied significantly for treatments. The availability of K in the soil got decreased as the crop growth advanced, which could be attributed to the uptake of K by the crop.

As observed with available N and P, the initial fertility status would also have made the difference. Among the microbial inoculants, AM in combination with ZSB (234 kg ha^{-1}) had significantly higher available K, which was on par with M_3 (228 kg ha^{1}) and M_2 (227 kg ha^{-1}), while M_1 registered lower value of 220 kg ha^{-1}. The available K content measured at vegetative stage showed marked influence for the microbial inoculation, especially for combination of bacteria and fungus over untreated check. But, the effect due to the application of AM fungus (M_2) and ZSB (M_3) were similar. The probable reason for enhanced K availability for the microbial inoculation might be due to solubilization of K from micaceous minerals. This reasoning is in agreement with the report of Anthoniraj (2015).

Table 5. Graded levels of Zn with AM and ZSB on total phosphorus uptake (kg ha^{-1})

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1 Control	1.6	1.8	2.1	2.2	2.1	1.5	1.9	8.8	9.9	12.3	16.2	15.7	7.9	11.8	18.7	20.2	19.1	18.0	18.2	16.4	18.4
M_2 – AM	1.8	2.2	2.6	2.9	2.9	1.9	2.4	10.5	14.7	18.8	22.3	21.8	12.4	16.7	21.0	23.8	25.9	27.4	27.5	22.2	24.6
M_3 – ZSB	1.8	2.2	2.6	2.9	3.0	2.0	2.4	10.9	14	16.4	19.7	19.90	12.4	15.5	19.9	21.8	23.8	25.0	25.2	20.3	22.7
M_4 – M_{2+} M_3	2.4	2.9	3.6	4.1	4.3	2.8	3.3	16.3	21.9	25.7	30.0	29.4	19.0	23.7	23.3	27.4	28.4	32.0	32.3	26.3	28.3
Mean	1.9	2.2	2.7	3.0	3.1	2.0	2.5	11.6	15.1	18.3	22.0	21.7	12.9	16.9	20.7	23.3	24.3	25.6	25.8	21.3	23.5

	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)
M	0.13	0.3	0.94	2.0	1.67	3.5
S	0.16	0.3	1.15	2.4	2.05	4.3
M x S	0.33	NS	2.30	NS	4.10	8.6

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

The Zn levels had also influenced the soil available K significantly. However, the foliar application of $ZnSO_4$ (S_6) and control (S_1) were on par and recorded significantly lower values of available K than the higher Zn level. Graded doses of $ZnSO_4$ application correspondingly increased the soil available K (222, 231, 239 and 242 kg ha^{-1} for S_2, S_3, S_4 and S_5, respectively). The highest availability of K in soils might be probably due to the synergistic effect between Zn and K. The readily available form of K from clay lattice due to the cation exchange might have accounted for higher K availability. The critical level of K depends on the soil cation exchange capacity and varies depending on crop type and other management practices (Aref, 2011). The interaction effect of M x S on soil available K was significant. The S_1 and S_6 treatments, which were on par had the lowest available K. The increased doses of soil application of $ZnSO_4$ had favourable influence in the soil available K at M_1 and M_4. However, at M_2 and M_3, the increase beyond 37.5 kg ha^{-1} of $ZnSO_4$ application had no significant positive impact on soil available K. Similar results were observed at tasselling and post harvest stages.

Table 6. Graded levels of Zn with AM and ZSB on total potassium uptake (kg ha^{-1})

Treatments	Vegetative stage							Tasselling stage							Harvest stage						
	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1 Control	9.0	10.9	13.5	13.0	14.0	9.7	11.7	50	64	84	112	120	54	81	101	141	153	162	164	137	143
M_2 – AM	10.7	13.0	16.1	22.0	23.6	12.7	16.3	61	81	102	120	127	70	93	123	142	151	164	166	139	148
M_3 – ZSB	12.9	15.9	20.2	20.6	23.5	15.9	18.1	71	90	103	113	120	80	96	137	152	165	176	175	148	159
M_4 – M_{2+} M_3	16.2	18.7	23.6	24.7	30.5	20.1	22.3	94	115	128	145	155	102	123	141	162	169	198	200	157	171
Mean	12.2	14.6	18.3	20.1	22.9	14.6	17.1	69	87	104	122	130	76	98	125	149	160	175	176	145	155

	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)
M	1.01	2.1	4.54	9	2.18	5
S	1.24	2.6	5.56	12	10.95	23
M x S	2.47	NS	11.11	NS	22.38	47

S_1: 0, S_2: 12.5, S_3: 25, S_4: 37.5, S_5: 50 kg ha^{-1} of soil application and S_6 @ 0.5% foliar spray of $ZnSO_4$ on 45 and 65 DAS

N, P and K uptake

From the Table 4, 5 and 6, it may be seen that interaction between microbial inoculation of AM fungus (M_2), ZSB (M_3) and their combinations (M_4) under graded levels of $ZnSO_4$ application increased the N, P and K uptake in maize crop grown in black soil. The highest uptake (155, 32.3 and 200 kg ha^{-1} for N, P and K, respectively) was recorded in the treatment combination of microbial inoculation (AM + ZSB) with the highest dose of $ZnSO_4$ @ 50 kg ha^{-1}. The minimum of N, P and K uptake (92, 18.7 and 101kg ha^{-1}, respectively) was found in control. Dry matter production was found to be increased by microbial inoculation and graded levels of $ZnSO_4$, which in turn increased the N, P and K uptake by maize crop. The probable reason might be the increase in soil nutrient status, which could have favoured the uptake. The results corroborate with the findings of Kaur *et al.* (2014) and Kanimozhi *et al.* (2015), who reported the increased nutrient uptake due to the application of microbial inoculation to the crop.

Conclusion

The combined application of *Glomus intraradices* (AM) and zinc solubilizing *Bacillus* sp. had enhanced soil available NPK at vegetative, tasselling and harvesting stage of crop growth. Increased doses of $ZnSO_4$ application had positive effect on the soil available N and K at all stages of observation. Among the microbial inoculations, application of AM fungus along with ZSB (M_4) had recorded the highest available P. Influence of graded doses of $ZnSO_4$ on soil available P was not spectacular. Application of AM and ZSB along with 50 kg of $ZnSO_4$ ha^{-1} had recorded the highest soil available NPK. Application of AM + ZSB (M_4) also registered the highest uptake of NPK by maize crop in black soil. Graded levels of Zn application enhanced the uptake of NPK correspondingly. However, the increase was not significant beyond 25 kg of ZnSO4 ha^{-1}.

References

Amanullah, M., T. Ananthi, K.S. Subramanian and P. Muthukrishnan. 2011. Influence of mycorrhiza, nitrogen and phosphorus on growth, yield and economics of hybrid maize. *Madras Agric. J.,* **98 (1-3):**62-66.

Ananthi, T. 2010. Response of hybrid maize (*Zea mays* L.) to mycorrhizal inoculation at varying nitrogen and phosphorus levels. M.Sc. (Ag.) Thesis, TNAU, Coimbatore.

Anthoniraj, S. 2014. Biosolubilizers – A boon to farmers. In: Plant - microbe interactions. (K. Ramasamy and K. Kumar (Ed)) New India Publ. Agency, New Delhi. pp: 383- 394.

Aref, F. 2011. The effect of boron and zinc application on concentration and uptake of nitrogen, phosphorous and potassium in corn grain.*Indian J. Sci. Technol.,* **4(7)**: 785-791.

Balakrishnan, N. 2011. Role of arbuscular mycorrhizal fungus (*Glomus intraradices* Schenck and Smith) symbiosis in biofortification of micronutrients in maize (*Zea mays* L.) Grain. Ph.D Thesis**,** Tamil Nadu Agricultural University, Coimbatore.

Gomez, K.A. and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New Delhi. pp: 680.

Jackson, M.L. 1973. Soil chemical analysis. Prentice Hall of India Private Ltd., New Delhi. pp: 56-70.

Kanimozhi, A., P. Santhy, N. Chandrasekaran and K. S. Subramanian. 2015. Response of maize plants to mycorrhizal colonization at varying level of phosphorus fertilization. In: Proceedings of the National Seminar on “Soil Resilience-2015” held at Madurai. pp: 146-147.

Kaur, R., A. Singh and J.S. Kang. 2014. Influence of Different Types Mycorrhizal Fungi on Crop Productivity. *Curr. Agri. Res. Jour.,* **2(1):** 51-54.

Koide, R.T., and Z. Kabir. 2000. Extraradical hyphae of the mycorrhizal fungus *Glomus intraradices* can hydrolyse organic phosphate. *New Phytol.***148:** 511-517.

Lindsay, W.L. and W.A. Norvell. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.,* **42:** 421-428.

Olsen, S.R., C.V. Cole, F.S. Watenabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Circ. 939, U.S. Govt. Printing Office, Washington, DC.

Subbiah, B.V. and G.C. Asija. 1956. A rapid procedure for estimation of available nutrients in soils. *Curr. Sci.,* **25:** 259 - 260.

Subramanian, K.S. and C. Charest. 1999. Acquisition of N by external hyphae of an arbuscular mycorrhizal fungus and its impact on physiological responses in maize under drought-stressed and well-watered conditions. *Mycorrhiza.***9**: 69–75.

Walkley, A and C.A. Black. 1934. An examination of the Deglgareff method for determining soil organic matter and proposed modification of chromic acid titration method. *Soil Sci.,* **37:** 29 - 38.

Received after revision: September 26, 2016 ; Accepted: September 30, 2016