Madras Agric. J., 2019; doi:10.29321/MAJ 2019.000298

RESEARCH ARTICLE

Impact of Sources, Levels of Zinc and Zinc Solubilizing Bacteria on the Growth and Yield of Maize in Calcareous Soil

Bimal Glory Babu*[1], Malathi, P[3], Chitdeshwari, T[1] and Balachandar, D[2]
*[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore –641 003.
[2]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore –641 003.
[3]Department of Natural Resource Management, Horticultural College and Research Institute, Periyakulam – 625 604.

Received : 01st November, 2018
Revised : 15th July, 2019
Accepted : 16th July, 2019

ABSTRACT

A pot culture experiment was conducted with TNAU maize hybrid CO 6 at Tamil Nadu Agricultural University, Coimbatore to evaluate the effect of application of zinc and zinc solubilizing bacteria on the growth and productivity of maize in calcareous soil. The experimental soil was a black calcareous soil with clay loam texture, which belongs to Periyanaickenpalayam series (Typic Haplustert). The experiment was laid out in factorial completely randomized design (FCRD) with three factors replicated thrice. The treatments consisted of two sources of Zn ($ZnSO_4$ and $Zn_3(PO_4)_2$) with three levels (0, 5, 7.5 kg Zn ha^{-1}), with and without zinc solubilizing bacteria (ZSB). Among the sources, $ZnSO_4$ performed better than $Zn_3(PO_4)_2$ with respect to growth, yield attributes and yield. Increasing levels of Zn had a favourable influence on maize crop and highest growth and yield parameters were recorded with 7.5 kg Zn ha^{-1}. With the application of 7.5 kg Zn ha^{-1}, 11.3% mean grain yield increase was observed over no Zn application. ZSB inoculation increased the mean grain and stover yield of maize by 4.2% over the treatments without ZSB inoculation. Considering the overall performance, application of 7.5 kg Zn ha^{-1} as $ZnSO_4$ along with ZSB was found to be the best Zn management strategy for enhancing maize growth and productivity in calcareous soil.

Keywords: *Calcareous soil, Zinc, Maize, Growth, Yield.*

INTRODUCTION

Maize, known as the 'Queen of cereals' occupies third position in production next to wheat and rice in the world. Besides providing nutrients for human beings and animals, it also serves as a raw material for the production of oil, starch, protein, alcoholic beverages and food sweeteners.Maize is grown in a wide range of environment, extending from extreme semi-arid to sub humid and humid regions. In India, it is grown in an area of 9,63,320 hectares with a production of about 25.89 million tonnes and productivity of 2689 kg ha^{-1}. In Tamil Nadu, it is grown in an area of 31,503 hectares with a production of 0.95 million tonnes (Indiastat., 2017).

Deficiency of zinc not only affects the crop yield, but also nutritional quality and human health. Application of water soluble inorganic Zn fertilizers such as zinc sulphate to soils is relatively ineffective since it is converted to unavailable forms such as $ZnCO_3$, $ZnFe_2O_4$ and $ZnSiO_4$. Microbial transformation of Zn from unavailable to available form is an important approach contributing to plant Zn nutrition. Among the plants, maize (*Zea mays L.*) is highly susceptible to Zn deficiency, particularly in calcareous soils, where high pH and high $CaCO_3$ content affect the Zn availability. Zn deficiency hinders maize growth resulting in decreased grain yield and quality(Behera *et al.*, 2015). Maize, considered as a good indicator crop of low soil Zn levels, receives the highest proportion of Zn fertilizer application in many countries.

As Zn availability is an important limiting factor in calcareous soils, it is imperative to evaluate the effect of Zn nutrition on maize growth and productivity. Hence a pot culture study was conducted to study the zinc management strategies for improving the maize growth and productivity in calcareous soil.

MATERIAL AND METHODS

A pot culture experiment was conducted in the Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore to study the impact of application of Zn and Zn solubilizing bacteria on the growth and yield of maize in calcareous soil. The experimental soil collected from Eastern block, TNAU, Coimbatore was a black calcareous soil with clay loam texture, which belongs to

---

*[1]Corresponding author's e-mail: bimalglorybabu93@gmail.com

Periyanaickenpalayam series and comes under the taxonomic classification fine, montmorillonitic, isohyperthermic, calcareous Typic Haplustert. The soil was air dried, processed and sieved using 2 mm sieve. Representative subsamples were drawn for the analysis of physical, chemical and physico-chemical properties of the soil by adopting the standard analytical procedures. The soil was alkaline in reaction (8.47) with permissible amount of soluble salts (0.31 dS m^{-1}). The experimental soil was moderately calcareous with a free $CaCO_3$ content of 12.0%. The organic carbon content of the soil was medium (5.4 g kg^{-1}).The soil was low in available N (232 kg ha^{-1}), medium in available P (17.9 kg ha^{-1}), high in available K (588 kg ha^{-1}), deficient in DTPA-Zn (0.59 mg kg^{-1}), DTPA-Fe (2.11 mg kg^{-1}), DTPA-Cu (0.79 mg kg^{-1}) and sufficient in DTPA-Mn (6.33 mg kg^{-1}).

The experiment was laid out in factorial completely randomized design (FCRD),with three factors *viz*.,sources of Zn ($ZnSO_4$ and $Zn_3(PO_4)_2$), levels of Zn (0, 5, 7.5 kg Zn ha^{-1}) and zinc solubilizing bacteria (ZSB) application (with and without ZSB) replicated thrice. Of the sources of Zn used, $ZnSO_4$ is soluble in water whereas $Zn_3(PO_4)_2$ is insoluble in water. Each pot was filled with 10 kg of soil and single plant was maintained in each pot. The ZSB (*Enterobacter cloacae*) strain cultivated in Bunt and Rovira medium supplemented with ZnO, prepared as inoculum was thoroughly mixed with soil with a final concentration of about 10^8 cfu per g. The major nutrients were applied as per fertilizer recommendation for maize hybrid @ 250:75:75 kg ha^{-1} in the form of urea, single super phosphate and muriate of potash. FYM was applied @ 12.5t ha^{-1}.

Biometric observations like plant height, leaf area, root length, root volume and root weight were recorded. The yield attributes such as length and girth of the cob, 100 grain weight, number of grains per cob, grain and stover yield were recorded. The length and girth of the cob was measured and expressed in cm. The number of grains was counted and 100 grain weight was recorded and expressed in grams. The weight of the grain (yield) from each treatment was calculated and expressed in g $plant^{-1}$. After drying, the stover yield was recorded and expressed in g $plant^{-1}$.The data obtained from the investigations were subjected to the analysis of variance to find out the significance. Wherever the treatment differences were found significant critical differences (CD) were worked out at 5% level with mean separation by least significant difference (LSD). Non-significant comparisons were indicated as NS.

RESULTS AND DISCUSSION

Growth parameters

Application of different sources, levels of Zn and ZSB significantly increased the plant height at all the growth stages of maize (Table 1). Among the

Table 1. Effect of sources, levels of Zn and ZSB on plant height at different growth stages of maize

Sources of Zn	Levels of Zn (kg ha^{-1})	Plant height (cm)											
		Vegetative				Flowering				Harvest			
		0	5.0	7.5	Mean	0	5.0	7.5	Mean	0	5.0	7.5	Mean
$ZnSO_4$	(+) ZSB	47.4	51.5	52.7	50.6	118	127	131	126	142	154	158	152
	(-) ZSB	44.1	49.6	51.5	48.4	110	123	128	121	132	149	155	145
	Mean	45.8	50.6	52.1	49.5	114	126	130	123	137	152	157	148
$Zn_3(PO_4)_2$	(+) ZSB	47.0	48.6	50.8	48.8	117	121	127	122	141	146	153	147
	(-) ZSB	44.4	46.9	49.2	46.8	111	117	123	117	133	141	148	141
	Mean	45.7	47.8	50.0	47.8	114	119	125	119	137	144	151	144
	Grand mean	45.7	49.2	51.1	48.7	114	122	127	121	137	148	154	14
			SEd		CD (P=0.05)		SEd		CD (P=0.05)		SEd		CD (P=0.05)
	S		0.62		1.28		1.55		3.19		1.86		3.84
	Z		0.62		1.28		1.55		3.19		1.86		3.84
	L		0.76		1.57		1.89		3.91		2.28		4.71
	SZ		0.88		NS		2.19		NS		2.63		NS
	ZL		1.08		NS		2.68		NS		3.23		NS
	SL		1.08		NS		2.68		NS		3.26		NS
	SZL		1.52		NS		3.79		NS		4.56		NS

*S – Sources of Zn; Z – Zinc Solubilising Bacteria (ZSB); L – Levels of Zn

Table 1a. Mean plant height at different growth stages of maize for ZSB application

ZSB	Growth stages: Plant height (cm)		
	Vegetative	Flowering	Harvest
(+) ZSB	49.7	124	149
(-) ZSB	47.6	119	143

different sources, $ZnSO_4$ when applied at higher rates (7.5 kg Zn ha^{-1}) recorded significantly the highest mean plant height of 52.1, 130 and 157 cm at vegetative, flowering and harvest stages of maize respectively. ZSB was found to significantly increase the plant height(49.7, 124 and 149 cm at vegetative, flowering and harvest stages respectively) (Table 1a). Improvement in the plant height on Zn application might be due to the formation of tryptophan which acts as the precursor of IAA, which is involved in the production of auxin (Hafeez *et al.*, 2013). IAA improves the plant growth through extending the root system and improving the absorbtion of water and nutrients (Kuan*et al.*, 2016).Interactions found to have non-significant improvement in plant height at all the growth stages.

Table 2. Effect of sources, levels of Zn and ZSB on leaf area of maize at different growth stages

Sources of Zn	Levels of Zn (kg ha^{-1})	Leaf area (cm^2 plant^{-1})							
		Vegetative				Flowering			
		0	5.0	7.5	Mean	0	5.0	7.5	Mean
$ZnSO_4$	(+) ZSB	697	748	764	736	2933	3209	3305	3149
	(-) ZSB	659	726	750	712	2752	3088	3221	3020
	Mean	678	737	757	724	2842	3148	3263	3084
$Zn_3(PO_4)_2$	(+) ZSB	691	714	740	715	2897	3053	3185	3045
	(-) ZSB	662	692	722	692	2789	2945	3089	2941
	Mean	677	703	731	704	2843	2999	3137	2993
	Grand mean	677	720	744	714	2842	3073	3200	3038
			SEd		CD (P=0.05)		SEd		CD (P=0.05)
	S		7.72		15.93		40.22		83.01
	Z		7.72		15.93		40.22		83.01
	L		9.45		19.51		49.26		101.67
	SZ		10.92		NS		56.88		NS
	ZL		13.37		NS		69.66		NS
	SL		13.37		NS		69.66		NS
	SZL		18.91		NS		98.52		NS

*S – Sources of Zn; Z – Zinc Solubilising Bacteria (ZSB); L – Levels of Zn

Table 2a. Mean leaf area at different growth stages of maize for ZSB application

ZSB / Growth stages	Leaf area (cm^2 plant^{-1})	
	Vegetative	Flowering
(+) ZSB	726	3097
(-) ZSB	702	2980

Table 3. Effect of sources, levels of Zn and ZSB on root growth at harvest stage of maize

Sources of Zn	Levels of Zn (kg ha^{-1})	Root length (cm)				Root volume (cm^3)				Root weight (g)			
		0	5.0	7.5	Mean	0	5.0	7.5	Mean	0	5.0	7.5	Mean
$ZnSO_4$	(+) ZSB	51.4	55.8	57.3	54.9	37.5	40.7	41.8	40.0	15.1	16.4	16.9	16.1
	(-) ZSB	48.1	53.7	55.9	52.6	35.1	39.1	40.8	38.3	14.2	16.0	16.4	15.5
	Mean	49.8	54.8	56.6	53.7	36.3	40.0	41.3	39.2	14.7	16.2	16.7	15.8
$Zn_3(PO_4)_2$	(+) ZSB	51.1	52.8	54.9	53.0	37.1	38.3	40.3	38.6	15.2	15.7	16.2	15.7
	(-) ZSB	48.3	50.9	53.5	50.9	35.4	37.2	38.9	37.2	14.3	15.1	15.9	15.1
	Mean	49.7	51.9	54.2	51.9	36.3	37.8	39.6	37.9	14.8	15.4	16.1	15.4
	Grand mean	49.7	53.3	55.4	52.8	36.9	38.8	40.4	38.5	14.7	15.8	16.4	15.6
			SEd		CD (P=0.05)		SEd		CD (P=0.05)		SEd		CD (P=0.05)
	S		0.673		1.390		0.491		1.014		0.199		0.410
	Z		0.673		1.390		0.491		1.014		0.199		0.410
	L		0.825		1.702		0.602		1.242		0.243		0.502
	SZ		0.952		NS		0.695		NS		0.281		NS
	ZL		1.166		NS		0.851		NS		0.344		NS
	SL		1.166		NS		0.851		NS		0.344		NS
	SZL		1.649		NS		1.204		NS		0.486		NS

*S – Sources of Zn; Z – Zinc Solubilising Bacteria (ZSB); L – Levels of Zn

Table 3a. Mean root growth at harvest stage of maize for ZSB application

ZSB	Root length (cm)	Root volume (cm^3)	Root weight (g)
(+) ZSB	53.9	39.3	16.0
(-) ZSB	51.8	37.8	15.3

$ZnSO_4$ was found to increase the leaf area significantly compared to $Zn_3(PO_4)_2$(724 and 3084 cm^2 $plant^{-1}$at vegetative and flowering stages respectively) (Table 2). Application of 7.5 kg ha^{-1} had significantly increased the leaf area (744 and 3200 cm^2 $plant^{-1}$) at vegetative and flowering stages of maize. Leaf area at all growth stages was also increased significantly with application of ZSB (726 and 3097 cm^2 $plant^{-1}$ at vegetative and flowering stages respectively) (Table 2a). Improved growth with ZSB inoculation might be due to the increase in availability of nutrients (Burd *et al.*, 2000).No significant effect of interaction among the treatments was seen at any of the growth stages of maize.

Table 4. Effect of sources, levels of Zn and ZSB on the yield attributes of maize

Sources of Zn	Levels of Zn (kg ha^{-1})	Cob length (cm)				Cob girth (cm)				No of grains per cob				100 grain weight(g)			
		0	5.0	7.5	Mean	0	5.0	7.5	Mean	0	5.0	7.5	Mean	0	5.0	7.5	Mean
$ZnSO_4$	(+) ZSB	13.1	14.4	14.6	14.0	7.49	8.14	8.36	8.00	250	271	278	266	30.9	31.7	31.9	31.5
	(-) ZSB	12.3	13.7	14.4	13.5	7.02	7.85	8.15	7.67	233	263	274	256	30.5	31.6	31.8	31.3
	Mean	12.7	14.1	14.5	13.8	7.26	8.00	8.26	7.84	241	267	276	261	30.7	31.6	31.9	31.4
$Zn_3(PO_4)_2$	(+) ZSB	13.0	13.6	14.2	13.6	7.42	7.68	8.05	7.72	247	258	270	258	31.1	31.5	31.6	31.4
	(-) ZSB	12.3	13.1	13.6	13.0	7.08	7.40	7.79	7.43	236	247	261	248	30.6	31.5	31.4	31.2
	Mean	12.7	13.4	13.9	13.3	7.25	7.54	7.92	7.57	241	252	265	253	30.9	31.5	31.5	31.3
	Grand mean	12.7	13.7	14.2	13.5	7.25	7.77	8.09	7.70	241	259	271	257	30.8	31.6	31.7	31.4
			SEd		CD (P=0.05)		SEd		CD(P=0.05)		SEd		CD (P=0.05)		SEd		CD (P=0.05)
	S		0.17		0.36		0.10		0.20		3.28		6.77		0.41		NS
	Z		0.17		0.36		0.10		0.02		3.28		6.77		0.41		NS
	L		0.21		0.44		0.12		0.25		4.01		8.30		0.50		NS
	SZ		0.24		NS		0.14		NS		4.64		NS		0.58		NS
	ZL		0.30		NS		0.17		NS		5.68		NS		0.71		NS
	SL		0.30		NS		0.17		NS		5.68		NS		0.71		NS
	SZL		0.42		NS		0.24		NS		8.04		NS		1.00		NS

*S – Sources of Zn; Z – Zinc Solubilising Bacteria (ZSB); L – Levels of Zn

Table 4a. Mean yield attributes values for ZSB application in maize

ZSB	Cob length (cm)	Cob girth (cm)	No of grains per cob	100 grain weight(g)
(+) ZSB	13.8	7.86	263	31.46
(-) ZSB	13.2	7.55	252	31.24

Root growth (length, volume and weight) on application of different sources, levels of Zn and ZSB was also found to show a positive result (Table 3). Among the sources tried, $ZnSO_4$recorded higher root length (53.7 cm), root volume (39.2 cm^3) and root weight (15.8 g). A significant improvement in root length (55.4 cm), root volume (40.4 cm^3) and root weight (16.4 g) was also noticed with application of 7.5 kg Zn ha^{-1}. This might be due to the better solubilization of $ZnSO_4$ compared to $Zn_3(PO_4)_2$ resulting in comparatively higher available Zn and hence increase in the production of plant growth hormones like auxin which enhances the growth. Addition of ZSB also increased the root length (53.9 cm), root volume (39.3 cm^3) and root weight (16 g) of maize (Table 3a). The enhancement in the root volume may be due to the phytohormones produced by the microbes (Goteti *et al.*, 2013). Apart from the solubilization of insoluble Zn sources, many ZSB also possess the property of production of plant growth promoting substances and siderophores (Shruthi, 2013). Similar results were also reported by Richardson (2001) where inoculation of PGPR effectively increased surface area of roots and root weight.

Levels of Zn had a positive impact on the dry matter production of maize, being highest at 7.5 kg Zn ha^{-1}(145 g $plant^{-1}$) (Table 5). This showed that improvement in soil Zn with better Zn nutrition ultimately resulted in higher dry matter production. Similar findings were also recorded by Preetha and Stalin (2014). $ZnSO_4$ was found to be a better source in improving the dry matter production than

$Zn_3(PO_4)_2$ (140 g plant^{-1}). This might be due to the better solubility of the former that resulted in greater availability and uptake of Zn in the early stages of maize growth. The importance of enriching the soil with available Zn during the early growth of maize is recognized by the positive and highly significant correlation existing between DMP and soil available Zn at vegetative stage (0.906**) (Table 6). ZSB application also recorded a higher DMP (141 g plant^{-1}) when compared to control (Table 5a). This can be attributed to the better solubility of Zn and hence increase in its availability to plant which leads to an increase in the dry matter production. Similar results were also reported by Shruthi (2013).

Table 5. Effect of sources, levels of Zn and ZSB on the grain, stover yield and dry matter production (DMP) of maize

Sources of Zn	Levels of Zn (kg ha^{-1})	Grain yield (g plant^{-1})				Stover yield (g plant^{-1})				DMP (g plant^{-1})			
		0	5.0	7.5	Mean	0	5.0	7.5	Mean	0	5.0	7.5	Mean
$ZnSO_4$	(+) ZSB	57.0	61.5	63.1	60.5	88.0	95.1	97.7	93.6	135	146	150	143
	(-) ZSB	53.0	59.3	61.6	58.0	82.1	91.6	95.3	89.7	126	140	146	137
	Mean	55.0	60.4	62.4	59.3	85.1	93.4	96.5	91.7	130	143	148	140
$Zn_3(PO_4)_2$	(+) ZSB	56.2	58.2	60.8	58.4	86.8	90.1	94.2	90.4	133	138	144	138
	(-) ZSB	53.4	56.1	58.9	56.2	82.6	86.8	91.1	86.9	127	133	140	133
	Mean	54.8	57.2	59.9	57.3	84.7	88.5	92.7	88.6	130	135	142	136
	Grand mean	54.9	58.8	61.1	58.3	84.9	90.9	94.6	90.1	130	139	145	138
			SEd		CD (P=0.05)		SEd		CD (P=0.05)		SEd		CD (P=0.05)
	S		0.74		1.53		1.15		2.37		1.76		3.63
	Z		0.74		1.53		1.15		2.37		1.76		3.63
	L		0.91		1.88		1.41		2.90		2.16		4.45
	SZ		1.05		NS		1.62		NS		2.49		NS
	ZL		1.29		NS		1.99		NS		3.05		NS
	SL		1.29		NS		1.99		NS		3.05		NS
	SZL		1.82		NS		2.81		NS		4.31		NS

*S – Sources of Zn; Z – Zinc Solubilising Bacteria (ZSB); L – Levels of Zn

Table 5a. Mean grain, stover yield and dry matter production (DMP) of maize for ZSB application

ZSB	Grain yield (g plant^{-1})	Stover yield (g plant^{-1})	DMP (g plant^{-1})
(+) ZSB	59.5	92.0	141
(-) ZSB	57.1	88.3	135

Yield attributes of maize

$ZnSO_4$ applied @ 7.5 kg Zn ha^{-1} was found to have a positive effect on cob length (14.5 cm) and cob girth (8.26 cm) compared to $Zn_3(PO_4)_2$ (Table 4). Inoculation of ZSB also found to have profoundly increased the cob length (13.8 cm)and cob girth (7.86 cm) of maizeas observed from the data recorded (Table 4a). This is in agreement with the earlier findings of Tahir *et al.*, 2009, who recorded a positive response in cob length with increasing levels of Zn. Interactions failed to create any significant difference in cob length of maize. This observation could be further strengthened by the significant and positive relationship between soil available Zn at vegetative and flowering stages with cob length (0.912** and 0.894**) and cob girth (0.911** and 0.885**) (Table 6).

Significant difference was noticed in the number of grains per cob with application of different sources, levels of Zn and ZSB (Table 4). $ZnSO_4$ @7.5 kg Zn ha^{-1} recorded more no. of grains per cob (276) compared to $Zn_3(PO_4)_2$. Moussa and Barsoum (1995)recorded that no. of grains per cobincreased due to Zn fertilization. Similar results was also reported byTalukder *et al.* (2011).This fact could be supported by the highly significant and positive relationship between no. of grains per cob and Zn uptake (0.983**) (Table 6). Application of ZSB exerted significant influence on the no. of grains per cob(263) (Table 4a). Interactions were found to show non-significant difference in the no. of grains per cob.

No significant variation in 100 grain weight of maize was found among the treatments with the application of different levels, sources of Zn and ZSB. Hundred grain weight of maize ranged between 30.5 and 31.9 g.

Grain and stover yield

The results showed that sources, levels of Zn and ZSB had significant influence on the grain and stover

Table 6. Correlation between soil available nutrients, nutrient uptake and yield attributes, yield of maize

	Cob length	Cob girth	No. of grains/cob	100 grain weight	Grain yield	Stover yield	DMP
soil P- Vegetative	0.637**	0.623**	0.611**	0.719**	0.631**	0.632**	0.632**
soil P-Flowering	0.627**	0.613**	0.609**	0.777**	0.624**	0.627**	0.626**
soil P-Harvest	0.581**	0.574**	0.575**	0.795**	0.581**	0.585**	0.584**
soil K-Vegetative	0.576**	0.583**	0.565**	0.837**	0.591**	0.591**	0.591**
soil K- Flowering	0.584**	0.588**	0.573**	0.823**	0.596**	0.597**	0.597**
soil K- Harvest	0.572**	0.578**	0.562**	0.874**	0.587**	0.586**	0.586**
soil Zn- Vegetative	0.912**	0.911**	0.912**	0.533**	0.905**	0.906**	0.906**
soil Zn- Flowering	0.894**	0.885**	0.888**	0.540**	0.881**	0.884**	0.883**
soil Zn- Harvest	0.835**	0.828**	0.828**	0.491**	0.828**	0.832**	0.830**
soil Fe- Vegetative	0.545**	0.551**	0.531**	0.826**	0.554**	0.556**	0.555**
soil Fe- Flowering	0.501**	0.508**	0.499**	0.817**	0.517**	0.519**	0.518**
soil Fe- Harvest	0.637**	0.649**	0.628**	0.729**	0.655**	0.656**	0.656**
soil Mn- Vegetative	0.632**	0.637**	0.619**	0.878**	0.644**	0.644**	0.644**
soil Mn- Flowering	0.617**	0.622**	0.607**	0.886**	0.630**	0.630**	0.630**
soil Mn- Harvest	0.623**	0.630**	0.613**	0.897**	0.637**	0.638**	0.637**
soil Cu- Vegetative	0.750**	0.752**	0.738**	0.892**	0.760**	0.760**	0.760**
soil Cu- Flowering	0.648**	0.646**	0.628**	0.890**	0.654**	0.655**	0.654**
soil Cu- Harvest	0.684**	0.690**	0.671**	0.875**	0.697**	0.697**	0.697**
P-uptake	0.427**	0.422**	0.425**	0.669**	0.433**	0.436**	0.435**
K-uptake	0.878**	0.886**	0.874**	0.936**	0.888**	0.889**	0.889**
Zn-uptake	0.981**	0.987**	0.983**	0.855**	0.987**	0.987**	0.987**
Fe-uptake	0.849**	0.856**	0.842**	0.923**	0.858**	0.859**	0.859**
Mn-uptake	0.876**	0.884**	0.873**	0.935**	0.887**	0.887**	0.887**
Cu-uptake	0.855**	0.861**	0.847**	0.901**	0.863**	0.864**	0.864**

yield of maize (Table 5). Comparing different sources, the highest mean grain and stover yield were recorded with application of ZnSO$_4$. Application of ZnSO$_4$ registered a mean grain and stover yield increase of 3.5 per cent over Zn$_3$(PO$_4$)$_2$ application. The readily soluble nature of ZnSO$_4$ might have ensured sufficient soil available Zn at the early stages of the crop growth. Among the levels of Zn, 7.5 kg Zn ha^{-1} registered the highest mean grain and stover yield followed by 5 kg Zn ha^{-1}.This could be further supported by the highly significant and positive relationship observed between grain yield (0.905**) and stover yield (0.906**) and soil available Zn at vegetative stage (Table 6).This showed the necessity of Zn fertilization to maize crop to achieve the desired yield level particularly in soils with low Zn status. The active role of Zn in enhancing maize yield has already been documented by Behera *et al.*(2015). Increase in grain yield with increasing levels of Zn was reported by Ruffo *et al.*(2016). ZSB application significantly increased the grain and stover yield of maize (Table 5a).The above results are in agreement with Shabaz *et al.*(2015) who recorded higher grain and stover yield with application of 3.6 g ZnSO$_4$ kg^{-1} seed. Zn uptake exerted highly significant and positive influence on grain. yield (0.987**) and stover yield (0.987**). The application of ZnSo$_4$ with ZSB marked by increase, the above ground shoot Zn uptake and root Zn uptakes as reported by Perumal et al. (2019).

CONCLUSION

From the foregoing results, it could be inferred that Zn fertilization along with ZSB markedly influenced the growth, yield attributes and yield of maize. It could be concluded that ZnSO$_4$ addition @ 7.5 kg Zn ha^{-1} along with ZSB (*Enterobacter cloacae*) was considered to be the best Zn management strategy in calcareous soil for obtaining higher yield of maize crop.

REFERENCES

Behera, S.K., Shukla, A.K., Singh, M., Wanjari, R.H. and P. Singh. 2015. Yield and zinc, copper, manganese and iron concentration in maize (*Zea Mays L*) grown on Vertisol as influenced by zinc application from various zinc fertilizers. *Journal of plant nutrition,* **38(10)**: 1544-1557.

Burd, G. I., Dixon, D.G. and B.R. Glick. 2000. Plant growth-promoting bacteria that decrease heavy metal toxicity in plants. *Canadian journal of microbiology,* **46(3)**: 237-245.

Goteti, P. K., Emmanuel, L. D. A., Desai, S. and M. H. A. Shaik. 2013. Prospective zinc solubilising bacteria for enhanced nutrient uptake and growth promotion in maize (*Zea Mays L.*). *International journal of microbiology.*

Hafeez, B., Khanif, Y.and M. Saleem. 2013. Role of zinc in plant nutrition-a review. *American journal of experimental Agriculture,* **3(2)**: 374.

Indiastat. 2017. Statistical data of India.

Kuan, K.B., Othman, R., Rahim, K.A. and Z.H. Shamsuddin. 2016. Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilisation of maize under greenhouse conditions. *PLoS One,* **11(3)**: e0152478.

Moussa, B. I. M. and M. S. Barsoum. 1995. The mutual effect of sulphur and magnesium under zinc application on maize at South Tahreer Province [Egypt]. *Annals of Agricultural Science, Moshtohor (Egypt).*

Perumal, M.D., Selvi, D., Chitdeswari, T. and D. Balachandar 2019. Enhanced zinc nutrient and enzyme activity of rice crop by zinc solubilizing bacteria with Zn sources in Zn deficient rice soil. Madras Agricultural Journal. 106: 171-177.

Preetha, P. S. and P. Stalin. 2014. Different forms of soil zinc-their relationship with selected soil properties and contribution towards plant availability and uptake in maize growing soils of Erode district, Tamil Nadu. *Indian Journal of Science and Technology,* **7(7)**: 1018-1025.

Richardson, A. E. 2001. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Functional Plant Biology,* **28(9)**: 897-906.

Ruffo, M., Olson, R. and I. Daverede. 2016. Maize yield response to zinc sources and effectiveness of diagnostic indicators. *Communications in soil science and plant analysis,* **47(2)**: 137-141.

Shabaz, M. K., Ali, H., Sajjad, M., Malook, S., Shah, S.A.N. and Q. Ali. 2015. Effect of seed coating with boron and zinc of *Zea mays* for various yield traits. *Am. Eurasian J. Agric. Environ. Sci.*, **15 (7):** 1304-1311.

Shruthi, P. 2013. Studies on Zinc Solubilizing Bacteria and Their Effect on Growth and Yield of Maize *(Zea Mays L.).*M.Sc.(Ag) Thesis, UAS, Dharwad.

Tahir, M., Fiaz, N., Nadeem, M., Khalid, F. and M. Ali. 2009. Effect of different chelated zinc sources on the growth and yield of maize (*Zea mays L*). *Soil Environ,* **28**: 179-183.

Talukder, K., Ahmed, I., Islam, M., Asaduzzaman, M. and M. Hossain. 2011. Incubation studies on exchangable Zn for varying levels of added Zn under aerobic and anaerobic conditions in grey terrace soils, non calcarious floodplain soils and calcarious floodplain soils. *Journal of science Foundation,* **9(1-2)**: 9-15.