RESEARCH ARTICLE

Soil Properties and Zinc Bio Availability as Affected by Zinc Sources, Organics and Microbial Inoculant in a Sandy Clay Loam Soil

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ABSTRACT

The studyaimed to evaluate the efficiency of different sources of Zinc and organic manures with and without microbial inoculants on the bioavailability of Zinc in soil. Four different zinc sources namely $ZnSO_4$, $ZnPO_4$, ZnO, and Zn-EDTA, and two organic manures *viz*., farm yard manure (FYM) and Vermicompost (VC) were evaluated in the presence and absence of Zinc Solubilizing Bacteria (ZSB). Among the different combinations of the above factors, $ZnSO_4$+FYM+ZSB combination recorded a maximum reduction in pH (6.82) whereas, $ZnSO_4$+Vermicompost+ZSB recorded the highest Electrical Conductivity (EC) (0.4 dSm^{-1}). Regarding DTPA-Zn availability Zn-EDTA recorded the highest concentration in soil both as a sole and combined application with organic and microbes. The dehydrogenase activity was upsurged in organic applied treatments and was less in fertilizer applied treatments. Zinc oxide recorded maximum dissolution efficiency compared to other sources of Zinc.

Keywords: *Zn Sources; Organics; ZSB; Dissolution; Bioavailability*

Introduction

The application of micronutrient fertilizer through synthetic sources significantly increases the cost of agricultural production. The fate of applied micronutrient fertilizers gone through various soil reactions which reduces its efficacy (less than 5%) and sustainability as a nutrient source. Organic carbon in the soil both directly and indirectly enhances the efficacy of the applied fertilizers (Ye *et al*., 2020). The nature of organics alters the physical, chemical, and biological properties of the soils, leading to increased bioavailability of soil nutrients (Walsh and McDonnell, 2012). Moreover,it also acts as a source of micronutrients on its microbial oxidation.

The different chemical forms of Zinc in soil were altered by synthetic and organic inputs. Normally the bioavailability of Zincin Indian soils was minimum. The rapidity in the distribution of soil-applied Zinc to various forms was based on the property of the soil and source of applied Zinc. The increase in time diminishes the bioavailable Zinc in more number of soils (Lock and Janssen, 2003). Microbes can redistribute the fixed Zinc back to bio available through various mechanisms (Ribeiro *et al*., 2020).

The deficiency is not due to the absence of Zinc, but mainly by the soil factors that retard its dissolution (Cakmak, 2008). Soil inherent factors like pH, organic matter, calcareousness, texture, waterlogging, and applied major nutrient fertilizers influence zinc bioavailability. In neutral and alkaline pH, zinc availability was retarded (Rehman *et al*., 2012). At pH below 5.2, $Zn^{2+}$was dominant but at above 7.6, pH zinc precipitates form as $Zn(OH)_2$ and other fixed forms. The chemisorption, precipitation, and zinc adsorption on calcium carbonate surfaces, $ZnCO_3$ and iron oxides reduce its activity (Zachara *et al*., 1988 & Kiekens, 1995). Heavy textured soil had shown more adsorptive surface which retains more Zinc than light-textured soils (Sidhu sharma, 2010). An average of above 30 % of global soil and more than 50 % of Indian soils were deficient in Zinc (Shukla *et al*., 2021 ; Ahmad *et al*., 2012).

There are various synthetic sources of Zinc such as ZnO, ZnS, $ZnCO_3$, and $Zn(PO_4).4H_2O$. But the nature of the solubility over the source in soil was minimal

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(Alloway, 2009). The soil microbial community could be able to solubilize the components insoluble in soil water (Hafeez *et al*., 2013).

By enhancing the solubility of the above factors, a cost-effective replacement of currently available sources as a fertilizer input is possible. This paper describes the ability of various Zn sources with organics and microbes on nutrient bioavailability. The applied inputs in the soil also change the fertility and health of the soil. The combined effect of synthetic sources of Zn, organic manures, and microbes on physiochemical properties and soil nutrient bio availability were investigated in the study.

Materials and methods

The bulk soil was collected from the farmer's field Kalappatti, Coimbatore with a latitude and longitude of 11°05'56" N and 77°03'31"E. The initial soil analysis namely pH -Potentiometry (Jackson,1973), EC -Conductometry (Jackson, 1973), organic carbon - Chromic acid wet digestion (Walkey and Black, 1934), soil texture -International pipette (Piper, 1966), Cation exchange capacity - Neural Normal NH_4OAc- (Jackson, 1973) and available Zn- DTPA extract – AAS (Lindsay and Norvell, 1978) were analyzed.The soil was air dried, sieved in a 2 mm sieve, and an exact quantity of 200 g of soil was taken in each incubation bottle. The different inorganic zinc sources (Zinc sulphate, Zinc phosphate, Zinc oxide and Zn-EDTA) were applied in respected incubation bottles at the Zn equivalent to 5 kg ha^{-1}. Organic sources *viz*., farm yard manure (FYM) @ 12.5 t ha^{-1} and vermicompost of (5 t ha^{-1}) were added as per treatment. Zinc solubilizing bacterial strain of Pseudomonas chlororephis was cultured and mass multiplied in Luria-Bertani medium (500 mL ha^{-1}) equivalent, with the CFU of 1012 mL^{-1} was inoculated. Totally there were 30 treatments and three replications maintained. Control was maintained for each factor. The design of the experiment was factorial completely randomized design.

In order to maintain 75 per cent field capacity moisture, distilled water was equally applied to all treatments and replications. The incubation bottles were kept in a controlled environment to prevent evaporation and other external influences.

The total duration of incubation was 60 days and non-destructive sampling was followed. Soil samples were collected periodically on 1st, 15th, 30th, 45th and 60th days after incubation. The collected samples were air-dried, sieved and analyzed for pH,EC, DTPA-Zn, and Dehydrogenase (Triphenylte-trazolium chloride – Casida *et al*., 1964) enzyme activity. The dissolution efficiency of Zinc is calculated using the formulae.

$$\text{Dissolution Efficiency} = \frac{\text{(Zn (or/and) Organic Source with ZSB)}}{\text{(Zn (or/ and)Organic source with out ZSB}} \times 100$$

Results and Discussion

Soil pH and Electrical conductivity

The Zn sources alone treatments significantly influenced the soil reaction (Table 2). Among the Zn sources, $ZnSO_4$ recorded the minimum pH of 7.29 (higher reduction) and the maximum pH was observed with $ZnPO_4$ with a pH of 7.63 (less reduction) at the end of the incubation experiment. The effect of Zn sources treatment on soil pH was significant. Application of organics significantly diminishes the soil pH compared to unapplied treatments. Regardless of sources, ZSB + FYM recorded significantly higher reduction of soil pH (7.10) compared to Vermicompost (7.21). The combined application of $ZnSO_4$ +FYM+ZSB recorded a maximum reduction in soil pH (6.82) compared to other treatment combinations and it was followed by FYM + ZSB (7.03).The results were in line with the findings of Ayyar *et al.* (2019) and Zajaczkowska *et al.*(2020). The decrease of pH in organic applied treatment might be due to applied organics which substantially enhanced the microbial activity that led to secretion of organic acids and hence decreased the pH (Sarma *et al*., 2017).

Soil application of zinc sources affects Electrical Conductivity (Table 3). An increase of EC was observed in $ZnSO_4$ treatment and it was followed by Zn-EDTA. The lowest soil EC was observed in the control. A sudden decrease in EC was observed at 15 days after incubation irrespective of sources and ZSB. But in 30, 45 and 60 days after incubation, the EC increased in organics applied soils. The highest soil EC was observed with the combination of $ZnSO_4$+ Vermicompost+ZSB treatment (0.4 dSm^{-1}) and the lowest was observed in control (0.33 dSm^{-1}). Similar findings was reported by Nada *et al.* (2011), Tripathi *et al.*(2017),and Nasrin *et al.*(2019).The sudden decrease of Electrical Conductivity in organic applied treatment may be due to the buffering action of organic matter, which decreases the solution concentration of ionic species, decreasing the EC. In FYM, the significant increase in microbial activity leads to uptake of soluble salt by microorganisms for the growth of microbial cell mass leads to less EC when compared to vermicompost (Amalraj *et al.*, 2013).

Soil dehydrogenase activity

The soil dehydrogenase activity ranged from 2.8 to 4.8 µg TPF g^{-1} h^{-1} at initiation of incubation (Table 4) and at theend of the experiment, the range was from 2.2 to 5 µg TPF g^{-1} h^{-1}. Zn sources alone treatment did not significantly increase the dehydrogenase activity before incubation. A slight decrease in dehydrogenase activity was observed on Zn sources alone treatments. At the end of the experiment, the lowest dehydrogenase activity was observed in the control(2.2 µg TPF g^{-1} h^{-1}). A significant increase in dehydrogenase activity with organics applied treatments at all stages of incubation was observed however it was maximum at 15th days after incubation. The highest dehydrogenase activity was observed in treatment $ZnSO_4$+FYM+ ZSB (5.7µg Tpf g^{-1} h^{-1}) followed by$ZnSO_4$+FYM (5.6µg Tpf g^{-1} h^{-1}). At 30th, 45th, and 60th days after incubation, a linear reduction of dehydrogenase was observed in organic applied treatments. Among the combinations, on 60th day after incubation, $ZnSO_4$+FYM+ ZSB treatment recoded the highest dehydrogenase activity (5.0 µg Tpf g^{-1} h^{-1}). A similar conclusion was found with the results of Amalraj *et al*.(2013) and Kumar and singh, (2017). The soil dehydrogenase activity was higher in FYM applied soils compared to vermicompost, it may be due to the quantity of FYM applied to the soil (nearly double of vermicompost) which might have led to higher microbial activity. Moreover, FYM contain more soluble organic carbon than Vermicompost. The dehydrogenase activity was higher in Zinc applied treatments which may be due to the fact that Zinc is an essential component for microbial metabolism (Subramanian *et al.*, 2009; Burns, 1982).

DTPA-Zn availability

The applied sources, organics, and microbes significantly influenced the DTPA fraction of Zinc at all stages of the incubation period (Fig. 1 to 3). Except for control a rapid reduction of DTPA-Zn was observed in all zinc sources applied treatments at 15th day after incubation proceeding days of incubation, the reduction was very slow (Perumal *et al*.,2019). The maximum reduction was observed in zinc sulphate alone treatment. ZSB treatment significantly increased the soil available Zinc at 15, 30,45 and 60 days after incubation. Zinc oxide recorded the maximum dissolution efficiency on both organic applied and unapplied treatments. The percent efficiency was higher on organic applied treatments. At the end of the incubation experiment, ZnO + FYM + ZSB recorded 2.21 times increase in DTPA-Zn compared to ZnO alone treatment and was followed by $Zn(PO_4)$+FYM+ZSB (2.15 times higher than $Zn(PO_4)$ alone treatment). The lowest solubilisation efficiency was observed in the Zn-EDTA+FYM+ZSB treatment (1.20 times).

The highest soil available zinc content was observed in Zn-EDTA+FYM+ZSB treatment at all incubation intervals except 1st Day after incubation (Naik *et al*., 2008). A slight increase in DTPA-Zn was observed on 45th day after incubation in all organic applied soils. The lowest available Zinc was recorded in the control (0.433 mg kg^{-1}) at the end of the experiment. The availability of Zinc was higher in Zn-EDTA treatment due to the solubility and chelated nature of the fertilizer that retard the adsorption, chemisorption and fixation of Zinc to the soil sites (Yousra *et al.*, 2019). The ZnO shows higher dissolution efficiency compared to other sources. It may due to, the other sources like $ZnSO_4$ and Zn-EDTA maintain higher Zinc concentration in soil solution, it dimnishes the Zinc solubilizing bacterial count whereas,in ZnO maintains only lower concentration of soil solution Zinc which increases the Zinc solubilizing efficiency by increasing the bacterial count (Saravanan *et al.*, 2004). Moreover application of organic carbon facilitates the solubility of insoluble zinc oxide through the production of organic acids (Saravanan *et al*., 2004; Fasim *et al*., 2002). An increase in zinc content at 45th day may due to the release of nutrients from organic manure starting from 20 days after incubation as recorded by Dey *et al*. (2019).

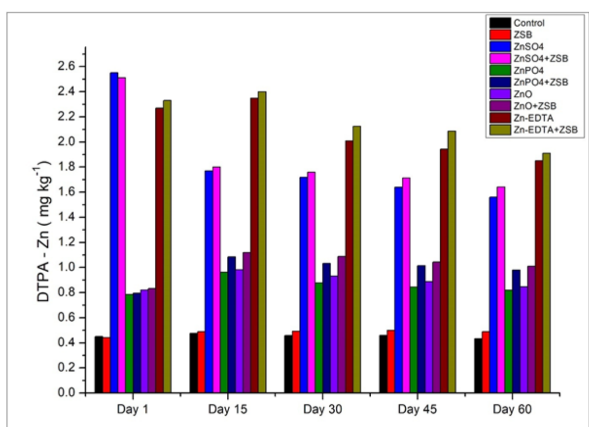

Figure 1. Zinc sources and ZSB on DTPA-Zn at different days of incubation

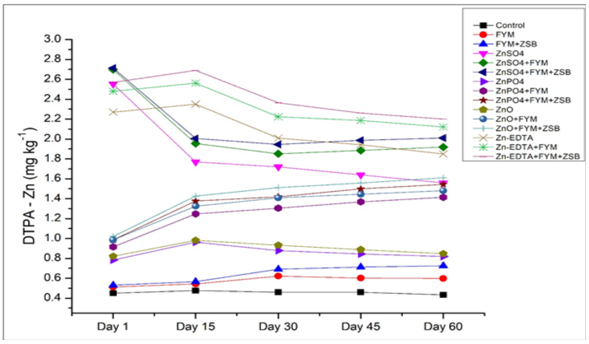

Figure 2. Zinc sources, FYM and ZSB on soil DTPA-Zn at different days of incubation

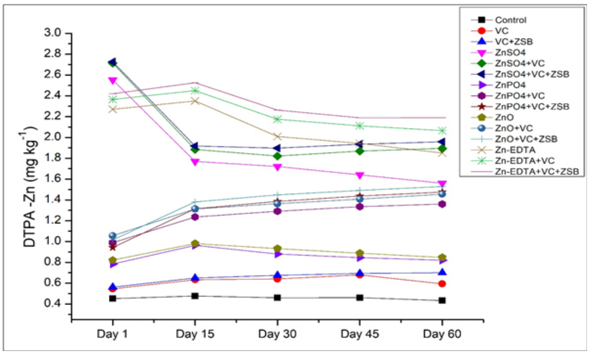

Figure 3. Zinc sources, Vermicompost and ZSB on soil DTPA-Zn at different days of incubation

Table 1. Characterization of experimental soil

S.No	Soil Properties	Value
1.	pH	7.59
2.	EC (dS m-1)	0.34
3.	Organic carbon (g kg^{-1})	6.1
4.	CEC (c mol (p+) Kg^{-1})	14.8
5.	Soil texture	Sandy Clay Loam
6.	Clay (%)	23.2
7.	Zna (mg kg-1)	0.534
8.	Znt (mg kg-1)	22.8

a indicates available Zn

t indicates total zinc

Table 2. Effect of Zinc sources, organics and bacterial inoculant on soil pH

Days	Sources		ZSB -				ZSB +		
		No M	VC	FYM	Mean	No M	VC	FYM	Mean
1	Control	7.60	7.53	7.41	7.51	7.58	7.40	7.34	7.44
	ZnSO4	7.44	7.40	7.38	7.41	7.41	7.34	7.29	7.34
	ZnPO4	7.63	7.45	7.42	7.50	7.70	7.40	7.37	7.49
	ZnO	7.74	7.42	7.40	7.52	7.62	7.39	7.35	7.45
	Zn-EDTA	7.62	7.49	7.37	7.49	7.68	7.49	7.30	7.49
	Mean	7.61	7.46	7.40	7.49	7.60	7.40	7.33	7.44
SEd	S – 0.04	O - 0.039	M - 0.089		SO-0.091	OM-0.07		SM-0.077	SOM-0.12
CD (0.05)	S – 0.105	O – 0.080	M – 0.061		SO- NS	OM- NS		SM - NS	SOM –NS
15	Control	7.52	7.44	7.33	7.43	7.50	7.33	7.26	7.36
	ZnSO4	7.32	7.35	7.23	7.30	7.30	7.27	7.14	7.25
	ZnPO4	7.82	7.40	7.53	7.58	7.71	7.34	7.31	7.45
	ZnO	7.62	7.36	7.33	7.44	7.53	7.33	7.31	7.39
	Zn-EDTA	7.57	7.43	7.32	7.44	7.50	7.36	7.28	7.38
	Mean	7.57	7.40	7.35	7.44	7.52	7.33	7.26	7.37
SEd	S – 0.054	O - 0.042	M - 0.094		SO-0.094	OM-0.060		SM-0.077	SOM-0.133
CD (0.05)	S – 0.109	O – 0.084	M – 0.069		SO- NS	OM- NS		SM - NS	SOM –NS
30	Control	7.57	7.35	7.22	7.38	7.43	7.26	7.20	7.30
	ZnSO4	7.27	7.31	7.20	7.23	7.25	7.23	7.03	7.18
	ZnPO4	7.79	7.36	7.45	7.53	7.64	7.39	7.28	7.44
	ZnO	7.55	7.32	7.27	7.38	7.45	7.28	7.26	7.33
	Zn-EDTA	7.47	7.35	7.26	7.36	7.45	7.32	7.25	7.34

	Mean	7.53	7.34	7.29	7.38	7.45	7.29	7.19	7.31
SEd	S - 0.070	O - 0.054	M - 0.044		SO-0.121	OM-0.77	SM- 0.099		SOM-0.171
CD (0.05)	S – 0.140	O – 0.108	M –NS		SO- NS	OM- NS	SM- NS		SOM- NS
45	Control	7.55	7.30	7.18	7.34	7.40	7.20	7.12	7.24
	ZnSO4	7.25	7.25	7.13	7.18	7.21	7.18	6.99	7.14
	ZnPO4	7.72	7.30	7.39	7.47	7.58	7.27	7.25	7.37
	ZnO	7.50	7.28	7.24	7.34	7.37	7.22	7.21	7.27
	Zn-EDTA	7.61	7.31	7.21	7.38	7.39	7.27	7.18	7.28
	Mean	7.51	7.29	7.23	7.34	7.40	7.23	7.15	7.26
SEd	S – 0.085	O – 0.066	M – 0.054		SO- 0.148	OM- 0.094	SM- 0.121		SOM-0.209
CD (0.05)	S – 0.171	O – 0.132	M - ns		SO- NS	OM- NS	SM - NS		SOM- NS
60	Control	7.52	7.21	7.10	7.28	7.38	7.12	7.03	7.18
	ZnSO4	7.26	7.17	6.98	7.15	7.20	7.03	6.82	7.02
	ZnPO4	7.63	7.28	7.37	7.43	7.51	7.22	7.16	7.30
	ZnO	7.42	7.25	7.20	7.29	7.34	7.17	7.10	7.20
	Zn-EDTA	7.55	7.22	7.16	7.31	7.38	7.19	7.07	7.21
	Mean	7.48	7.23	7.16	7.29	7.36	7.15	7.04	7.18
SEd	S – 0.073	O - 0.057	M - 0.046		SO- 0.127	OM- 0.086	SM- 0.104		SOM - 0.180
CD (0.05)	S – 0.147	O - 0.114	M - 0.093		SO –NS	OM - NS	SM-NS		SOM –NS

The data Analysis of variance done by LSD test (P ≤0.05). CD: Critical Difference SEd: Standard Error of difference; S-Zn sources; O-Organics; M-Microbe; SOM- Interaction

Table 3. Effect ofZinc sources, organics and bacterial inoculant on soil EC (dSm^{-1})

Days	Sources		ZSB -				ZSB +		
		No M	VC	FYM	Mean	No M	VC	FYM	Mean
1	Control	0.32	0.33	0.34	0.33	0.33	0.34	0.35	0.34
	ZnSO4	0.34	0.34	0.36	0.35	0.33	0.35	0.35	0.34
	ZnPO4	0.33	0.35	0.35	0.34	0.32	0.34	0.35	0.34
	ZnO	0.34	0.34	0.35	0.34	0.33	0.35	0.34	0.34
	Zn-EDTA	0.34	0.36	0.36	0.35	0.33	0.36	0.35	0.35
	Mean	0.33	0.34	0.35	0.34	0.33	0.35	0.35	0.34
SEd	S - 0.003	O - 0.002	M - 0.002		SO-0.004	OM-0.003	SM- 0.004		SOM- 0.006
CD (0.05)	S - 0.005	O - 0.004	M - 0.003		SO-0.009	OM- NS	SM- NS		SOM- NS
15	Control	0.30	0.33	0.31	0.31	0.32	0.32	0.30	0.31
	ZnSO4	0.35	0.31	0.32	0.33	0.35	0.30	0.31	0.32
	ZnPO4	0.35	0.32	0.31	0.33	0.34	0.31	0.30	0.32
	ZnO	0.35	0.32	0.31	0.33	0.34	0.30	0.32	0.32
	Zn-EDTA	0.35	0.32	0.34	0.34	0.34	0.31	0.33	0.33
	Mean	0.34	0.32	0.32	0.33	0.34	0.31	0.31	0.32
SEd	S - 0.003	O - 0.002	M - 0.002		SO-0.004	OM-0.003	SM- 0.004		SOM- 0.006
CD (0.05)	S - 0.005	O - 0.004	M - 0.003		SO-0.009	OM- NS	SM- NS		SOM- NS
30	Control	0.33	0.34	0.33	0.33	0.35	0.33	0.31	0.33

	ZnSO4	0.35	0.37	0.35	0.36	0.34	0.35	0.33	0.34
	ZnPO4	0.36	0.34	0.32	0.34	0.33	0.34	0.32	0.33
	ZnO	0.35	0.35	0.34	0.35	0.35	0.34	0.32	0.34
	Zn-EDTA	0.33	0.35	0.33	0.34	0.34	0.34	0.32	0.33
	Mean	0.35	0.35	0.34	0.34	0.34	0.34	0.32	0.33
SEd	S - 0.003	O - 0.003	M - 0.002		SO-0.006	OM- 0.004	SM-0.005		SOM-0.008
CD (0.05)	S - 0.007	O - 0.005	M - 0.004		SO- NS	OM- NS	SM- NS		SOM- NS
45	Control	0.32	0.35	0.34	0.34	0.34	0.36	0.33	0.34
	ZnSO4	0.36	0.38	0.36	0.37	0.34	0.37	0.35	0.35
	ZnPO4	0.35	0.37	0.35	0.36	0.32	0.36	0.34	0.34
	ZnO	0.35	0.36	0.35	0.35	0.34	0.35	0.33	0.34
	Zn-EDTA	0.34	0.36	0.35	0.35	0.33	0.34	0.32	0.33
	Mean	0.34	0.36	0.35	0.35	0.33	0.36	0.33	0.34
SEd	S - 0.003	O - 0.002	M - 0.002		SO-0.005	OM- 0.003	SM-0.004		SOM-0.007
CD (0.05)	S - 0.006	O - 0.005	M - 0.004		SO- NS	OM- NS	SM- NS		SOM- NS
60	Control	0.33	0.36	0.35	0.35	0.34	0.37	0.36	0.36
	ZnSO4	0.35	0.39	0.37	0.37	0.36	0.40	0.38	0.38
	ZnPO4	0.34	0.37	0.36	0.36	0.33	0.39	0.37	0.36
	ZnO	0.33	0.37	0.36	0.35	0.34	0.38	0.37	0.36
	Zn-EDTA	0.34	0.38	0.37	0.36	0.35	0.39	0.38	0.37
	Mean	0.34	0.37	0.36	0.36	0.34	0.39	0.37	0.37
SEd	S - 0.003	O - 0.002	M - 0.002		SO-0.005	OM- 0.003	SM-0.004		SOM-0.007
CD (0.05)	S - 0.006	O - 0.005	M - 0.004		SO- NS	OM- 0.006	SM- NS		SOM- NS

The data Analysis of variance done by LSD test (P ≤0.05). CD: Critical Difference SEd: Standard Error of difference; S-Zn sources; O-Organics; M-Microbe; SOM- Interaction

Table 4.Effect of Zinc sources, organics and bacterial inoculant on soil Dehydrogenase (µg TPF g^{-1} h^{-1}) activity

Days	Sources		ZSB -				ZSB +		
		No M	VC	FYM	Mean	No M	VC	FYM	Mean
1	Control	2.80	3.40	4.30	3.50	3.00	3.70	4.50	3.73
	ZnSO4	3.40	4.00	4.60	4.00	3.60	4.30	4.80	4.23
	ZnPO4	3.20	3.90	4.40	3.83	3.50	4.10	4.50	4.03
	ZnO	3.10	3.80	4.50	3.80	3.20	3.90	4.70	3.93
	Zn-EDTA	3.30	3.90	4.50	3.90	3.40	3.90	4.60	3.97
	Mean	3.16	3.80	4.46	3.81	3.34	3.98	4.62	3.98
SEd	S –0.036	O -0.028	M -0.023		SO- 0.062	OM-0.050	SM-0.039		SOM-0.087
CD (0.05)	S -0.071	O –0.055	M –0.045		SO- 0.124	OM- NS	SM- NS		SOM- NS
15	Control	2.72	4.20	5.20	4.04	2.80	4.40	5.40	4.20
	ZnSO4	3.20	4.80	5.60	4.53	3.50	5.00	5.70	4.73
	ZnPO4	3.10	4.60	5.50	4.40	3.30	4.70	5.60	4.53
	ZnO	3.00	4.40	5.40	4.27	3.10	4.60	5.50	4.40

	Zn-EDTA	3.20	4.60	5.60	4.47	3.20	4.70	5.70	4.53
	Mean	3.04	4.52	5.46	4.34	3.18	4.68	5.58	4.48
SEd	S –0.038	O -0.029	M -0.024	SO-0.066		OM-0.053	SM-0.041	SOM-0.093	
CD (0.05)	S –0.076	O –0.059	M –0.048	SO- NS		OM- NS	SM- NS	SOM- NS	
30	Control	2.60	4.00	5.00	3.87	2.70	4.20	5.10	4.00
	ZnSO4	3.00	4.60	5.30	4.30	3.20	4.80	5.40	4.47
	ZnPO4	2.90	4.40	5.20	4.17	3.20	4.50	5.30	4.33
	ZnO	2.80	4.30	5.20	4.10	3.00	4.40	5.30	4.23
	Zn-EDTA	2.90	4.40	5.20	4.17	3.10	4.50	5.30	4.30
	Mean	2.83	4.33	5.18	4.11	3.03	4.48	5.28	4.26
SEd	S –0.031	O -0.024	M -0.020	SO- 0.054		OM-0.044	SM-0.034	SOM-0.077	
CD (0.05)	S –0.063	O –0.049	M –0.040	SO-0.109		OM-NS	SM-NS	SOM- NS	
45	Control	2.30	3.70	4.80	3.60	2.50	3.80	4.90	3.73
	ZnSO4	2.80	4.40	5.10	4.10	3.00	4.60	5.20	4.27
	ZnPO4	2.70	4.30	4.90	3.97	3.00	4.40	5.00	4.13
	ZnO	2.50	4.10	4.90	3.83	2.70	4.30	5.00	4.00
	Zn-EDTA	2.70	4.30	4.90	3.97	2.90	4.40	5.00	4.10
	Mean	2.60	4.16	4.92	3.89	2.82	4.30	5.02	4.05
SEd	S –0.033	O -0.025	M -0.021	SO-0.057		OM-0.046	SM-0.036	SOM-0.080	
CD (0.05)	S –0.065	O -0.051	M -0.041	SO-0.113		OM-NS	SM-NS	SOM-NS	
60	Control	2.20	3.50	4.50	3.40	2.30	3.60	4.70	3.53
	ZnSO4	2.70	4.30	4.90	3.97	2.80	4.50	5.00	4.10
	ZnPO4	2.50	4.10	4.60	3.73	2.60	4.20	4.70	3.83
	ZnO	2.40	4.00	4.70	3.70	2.60	4.10	4.80	3.83
	Zn-EDTA	2.60	4.10	4.70	3.80	2.70	4.20	4.80	3.90
	Mean	2.48	4.00	4.68	3.72	2.60	4.12	4.80	3.84
SEd	S –0.036	O –0.028	M –0.023	SO-0.062		OM-0.051	SM-0.039	SOM-0.088	
CD (0.05)	S –0.072	O -0.056	M –0.045	SO-0.124		OM- NS	SM- NS	SOM- NS	

The data aAnalysis of variance done by LSD test (P ≤0.05). CD: Critical Difference SEd: Standard Error of difference; S-Zn sources; O-Organics; M-Microbe; SOM- Interaction

Conclusion

The perspective of Zinc fertilization is to maintain a higher solution concentration of Zinc. The maximum bioavailability of Zinc was observed by Zn-EDTA and by organics (FYM) with the presence of microbe. The combined effect of the above factors on soil produced superior effects on zinc availability. The solubilisation efficiency was higher in ZnO treatment, a good replacer for $ZnSO_4$ when it is applied with FYMand microbes. Without organic and microbe, zinc oxide was inferior in maintaining solution zinc concentration. It is concluded that the combined addition of Zn sources+ organics + microbes significantly influenced the pH, EC, Dehydrogenase activity and maintained sustainability on the bioavailability of Zinc than the sole application of the above factors.

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Ethics statement

There is no human and animal subject were engaged in this research. No specific permits were required for the described field studies

Originality and plagiarism

This manuscript produced only based on the original work of the authors.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required.

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