

RESEARCH ARTICLE ||

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

Subash Chandra Bose K^{1*}, Selvi D¹, Chitdeshwari T¹ and Balachandar D²

^{1*}Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641003

² Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore- 641 003

ABSTRACT

The study aimed 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 ZnSO₄, ZnPO₄, 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, ZnSO₄+FYM+ZSB combination recorded a maximum reduction in pH (6.82) whereas, ZnSO₄+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.

Received : 10th February, 2022

Revised : 18th February, 2022

Revised: 25th February, 2022

Accepted : 28th February, 2022

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 Zinc in 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, Zn²⁺ 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, ZnCO₃ 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, ZnCO₃, and Zn(PO₄)₂·4H₂O. But the nature of the solubility over the source in soil was minimal

(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 bioavailability 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 NH₄OAc- (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 chlororephus* 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 (Triphenyltetrazolium chloride - Casida *et al.*, 1964) enzyme activity. The dissolution efficiency of Zinc is calculated using the formulae.

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

Results and Discussion

Soil pH and Electrical conductivity

The Zn sources alone treatments significantly influenced the soil reaction (Table 2). Among the Zn sources, ZnSO₄ recorded the minimum pH of 7.29 (higher reduction) and the maximum pH was observed with ZnPO₄ 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 ZnSO₄ +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 ZnSO₄ 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 ZnSO₄+ 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 $\mu\text{g TPF g}^{-1} \text{h}^{-1}$ at initiation of incubation (Table 4) and at the end of the experiment, the range was from 2.2 to 5 $\mu\text{g TPF g}^{-1} \text{h}^{-1}$. 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 $\mu\text{g TPF g}^{-1} \text{h}^{-1}$). 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 $\text{ZnSO}_4 + \text{FYM} + \text{ZSB}$ (5.7 $\mu\text{g Tpf g}^{-1} \text{h}^{-1}$) followed by $\text{ZnSO}_4 + \text{FYM}$ (5.6 $\mu\text{g Tpf g}^{-1} \text{h}^{-1}$). 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, $\text{ZnSO}_4 + \text{FYM} + \text{ZSB}$ treatment recorded the highest dehydrogenase activity (5.0 $\mu\text{g Tpf g}^{-1} \text{h}^{-1}$). 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 $\text{Zn}(\text{PO}_4) + \text{FYM} + \text{ZSB}$ (2.15 times higher than $\text{Zn}(\text{PO}_4)$ 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 diminishes 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).

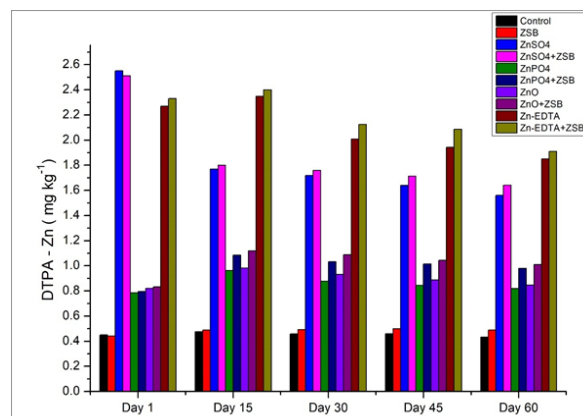


Figure 1. Zinc sources and ZSB on DTPA-Zn at different days of incubation

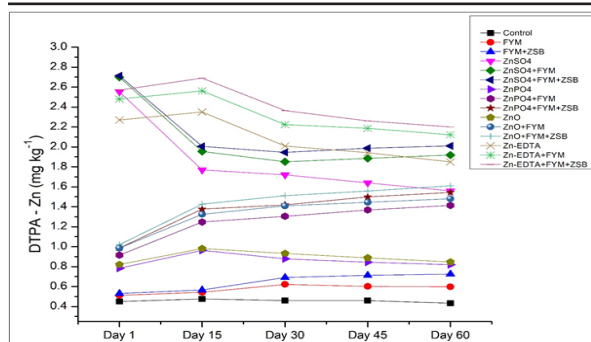


Figure 2. Zinc sources, FYM and ZSB on soil DTPA-Zn at different days of incubation

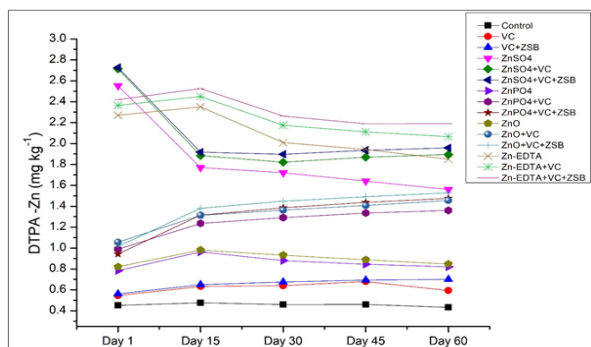


Figure 3. Zinc sources, Vermicompost and ZSB on soil DTPA-Zn at different days of incubation

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 | 0 - 0.039 | | M - 0.089 | SO-0.091 | OM-0.07 | | SM-0.077 | SOM-0.12 |
| CD (0.05) | S - 0.105 | 0 - 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 | 0 - 0.042 | | M - 0.094 | SO-0.094 | OM-0.060 | | SM-0.077 | SOM-0.133 |
| CD (0.05) | S - 0.109 | 0 - 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 | 0 - 0.054 | M - 0.044 | SO-0.121 | | OM-0.77 | SM- 0.099 | | SOM-0.171 |
| CD (0.05) | S - 0.140 | 0 - 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 | 0 - 0.066 | M - 0.054 | SO- 0.148 | | OM- 0.094 | SM- 0.121 | | SOM-0.209 |
| CD (0.05) | S - 0.171 | 0 - 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 | 0 - 0.057 | M - 0.046 | SO- 0.127 | | OM- 0.086 | SM- 0.104 | | SOM - 0.180 |
| CD (0.05) | S - 0.147 | 0 - 0.114 | M - 0.093 | SO - NS | | OM - NS | SM-NS | | SOM - NS |

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

Table 3. Effect of Zinc 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 | 0 - 0.002 | M - 0.002 | | SO-0.004 | OM-0.003 | | SM- 0.004 | SOM- 0.006 |
| CD (0.05) | S - 0.005 | 0 - 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 | 0 - 0.002 | M - 0.002 | | SO-0.004 | OM-0.003 | | SM- 0.004 | SOM- 0.006 |
| CD (0.05) | S - 0.005 | 0 - 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 | 0 - 0.003 | M - 0.002 | SO-0.006 | OM- 0.004 | SM-0.005 | SOM-0.008 | | |
| CD (0.05) | S - 0.007 | 0 - 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 | 0 - 0.002 | M - 0.002 | SO-0.005 | OM- 0.003 | SM-0.004 | SOM-0.007 | | |
| CD (0.05) | S - 0.006 | 0 - 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 | 0 - 0.002 | M - 0.002 | SO-0.005 | OM- 0.003 | SM-0.004 | SOM-0.007 | | |
| CD (0.05) | S - 0.006 | 0 - 0.005 | M - 0.004 | SO- NS | OM- 0.006 | SM- NS | SOM- NS | | |

The data Analysis of variance done by LSD test ($P \leq 0.05$). 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 ($\mu\text{g TPF g}^{-1} \text{h}^{-1}$) 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 | 0 -0.028 | M -0.023 | SO- 0.062 | OM-0.050 | SM-0.039 | SOM-0.087 | | |
| CD (0.05) | S-0.071 | 0 -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 | 0 -0.029 | M -0.024 | SO-0.066 | | OM-0.053 | SM-0.041 | | SOM-0.093 |
| CD (0.05) | S -0.076 | 0 -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 |
| | ZnSO ₄ | 3.00 | 4.60 | 5.30 | 4.30 | 3.20 | 4.80 | 5.40 | 4.47 |
| | ZnPO ₄ | 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 | 0 -0.024 | M -0.020 | SO- 0.054 | | OM-0.044 | SM-0.034 | | SOM-0.077 |
| CD (0.05) | S -0.063 | 0 -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 |
| | ZnSO ₄ | 2.80 | 4.40 | 5.10 | 4.10 | 3.00 | 4.60 | 5.20 | 4.27 |
| | ZnPO ₄ | 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 | 0 -0.025 | M -0.021 | SO-0.057 | | OM-0.046 | SM-0.036 | | SOM-0.080 |
| CD (0.05) | S -0.065 | 0 -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 |
| | ZnSO ₄ | 2.70 | 4.30 | 4.90 | 3.97 | 2.80 | 4.50 | 5.00 | 4.10 |
| | ZnPO ₄ | 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 | 0 -0.028 | M -0.023 | SO-0.062 | | OM-0.051 | SM-0.039 | | SOM-0.088 |
| CD (0.05) | S -0.072 | 0 -0.056 | M -0.045 | SO-0.124 | | OM- NS | SM- NS | | SOM- NS |

The data analysis of variance done by LSD test ($P \leq 0.05$). 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 ZnSO₄ when it is applied with FYM and 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.

Funding and Acknowledgment

The authors acknowledge the support and research facilities provided by Tamil Nadu Agricultural University.

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.

REFERENCES

- Ahmad, W., Watts, M. J., Imtiaz, M., Ahmed, I. and M. H. Zia. 2012. Zinc deficiency in soils, crops and humans: a review. *Agrochimica.*, 56(2): 65-97.
- Alloway, B.J. 2009. Soil factors associated with zinc deficiency in crops and humans., *Environ. Geochem. and health.*, 31(5): 537-548.
- Amalraj, E.L.D., Kumar, G.P., Ahmed, S. M. H., Abdul, R. and N. Kishore, 2013. Microbiological analysis of panchagavya, vermicompost, and FYM and their effect on plant growth promotion of pigeon pea (*Cajanus cajan* L.) in India. *Organic Agri.*, 3(1): 23-29.
- Ayyar, S., Appavoo, S., Basker, M., Pandiyarajan, P. and R. Kavimani, 2019. Effect of Zinc and microbial inoculation on soil enzyme activities for maize (*Zea mays* L.) in black soil. *Int. J. of Current Microbiol. and Appl. Sci.*, 8(8): 1804-14.
- Burns, R. G. 1982. Enzyme activity in soil: location and a possible role in microbial ecology. *Soil boil. And biochem.*, 14(5): 423-427.
- Cakmak, I. 2008. Enrichment of cereal grains with Zinc: agronomic or genetic biofortification. *Plant and soil.*, 302(1), 1-17.
- Casida L. E. Jr., Klein D. A. and Santoro T. 1964. Soil dehydrogenase activity. *Soil Science* 98, 371±376
- Dey, A., Srivastava, P. C., Pachauri, S. P. and A. K. Shukla. 2019. Time-dependent release of some plant nutrients from different organic amendments in a laboratory study. *Intl. J. of Recycling of Org. Waste in Agric.*, 8(1): 173-188.
- Fasim, F., Ahmed, N., Parsons, R. and G. M. Gadd. 2002. Solubilization of zinc salts by a bacterium isolated from the air environment of a tannery, *FEMS Microbiol. Letters.*, 213: 1-6.
- Hafeez, B. M. K. Y., Khanif, Y. M. and M. Saleem, 2013. Role of Zinc in plant nutrition-a review. *Am. j. of exp. Agric.*, 3(2): 374.
- Jackson M.L. 1973. Soil chemical analysis prentice hall of India. Pvt. Ltd. New Delhi. 1973;498.
- Kiekens, L. 1995. Zinc. In ALLOWAY, B.J. (ed.) Heavy Metals in Soils (2nd edn.). London : Blackie Academic and Professional., 284–305.
- Kumar, D. and A.P. Singh. 2017. Efficacy of potassium humate and chemical fertilizers on yield and nutrient availability patterns in soil at different growth stages of rice. *Commun. in Soil Sci. and Plant Anal.*, 48(3): 245-261.
- Lindsay, W. L. and W.A. Norvell, 1978. Development of a DTPA soil test for Zinc, iron, manganese, and copper. *Soil sci. soc. of Am. J.*, 42(3): 421-428.
- Lock, K. and C.R. Janssen. 2003. Influence of ageing on zinc bioavailability in soils. *Environ. Pollut.*, 126(3): 371-374.
- Nada, W. M., Van Rensburg, L., Claassens, S. and O. Blumenstein. 2011. Effect of vermicompost on soil and plant properties of coal spoil in the Lusatian region (Eastern Germany). *Commun. in Soil Sci. and Plant Anal.*, 42(16): 1945-1957.
- Naik, S. K. and D.K. Das, 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycling in Agroecosystems*, 81(3): 219-227.
- Nasrin, A., Khanom, S. and S. A. Hossain., (2019). Effects of vermicompost and compost on soil properties and growth and yield of Kalmi (*Ipomoea aquatica* Forsk.) in mixed soil. *Dhaka University J. of Biol. Sci.*, 28(1): 121-129.
- Perumal, M.D, Selvi, D. and D. Balachandar. 2017. Zinc dynamics in lowland rice soil as affected by organic manures and zinc fertilization. *Intl. J. of Chem. Stud.*, 5(1): 227-232.
- Piper C.S. 1966. Soil and plant analysis, Hans. Pub. Bombay. Asian Ed. 1966:368-74.
- Rehman, H.u., Aziz, T., Farooq, M., Wakeel, A. and Z. Rengel. 2012. Zinc nutrition in rice production systems: a review. *Plant Soil.*, 361: 203-226.
- Ribeiro, I. D. A., Volpiano, C. G., Vargas, L. K., Granada, C. E., Lisboa, B. B., and L. M. P. Passaglia. 2020. Use of mineral weathering bacteria to enhance nutrient availability in crops: A review. *Frontiers in Plant Science*, 11.
- Saravanan, V. S, Subramoniam S. R. and S.A. Raj.

2004. Assessing in vitro solubilization potential of different Zinc solubilizing bacterial (ZSB) isolates. *Brazilian J. of Microbiol.*, 35: 121-125.
- Sarma, B., Borkotoki, B., Narzari, R., Katakai, R. and N. Gogoi, 2017. Organic amendments: effect on carbon mineralization and crop productivity in acidic soil. *J. of Cleaner Production.*, 152: 157-166.
- Shukla, A. K., Behera, S. K., Prakash, C., Tripathi, A., Patra, A. K., Dwivedi, B. S. and A.K. Singh. 2021. Deficiency of phyto-available sulphur, Zinc, boron, iron, copper and manganese in soils of India. *Scientific reports*, 11(1): 1-13.
- Sidhu, G. S., and B.D. Sharma. 2010. Diethylenetriaminepentaacetic acid-extractable micronutrients status in soil under a rice-wheat system and their relationship with soil properties in different agroclimatic zones of indo-gangetic plains of India. *Commun. in Soil Sci. and Plant Anal.*, 41(1): 29-51.
- Subramanian, K. S., Tenshia, V., Jayalakshmi, K., and V. Ramachandran. 2009. Biochemical changes and zinc fractions in arbuscular mycorrhizal fungus (*Glomus intraradices*) inoculated and uninoculated soils under differential zinc fertilization. *Applied Soil Ecology*, 43(1): 32-39.
- Tripathi, P., Kashyap, S. D., Shah, S. and N.A. Pala. 2017. Effect of organic manure on soil physicochemical properties under fruit based agroforestry system. *Indian Forester.*, 143(1): 48-55.
- Walkley A, and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science.* 37(1):29-38.
- Walsh, E. and K.P. McDonnell. 2012. The influence of added organic matter on soil physical, chemical, and biological properties: a small-scale and short-time experiment using straw. *Arch. of agron. and soil sci.*, 58(1): S201-S205.
- Ye, L., Zhao, X., Bao, E., Li, J., Zou, Z. and K. Cao. 2020. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. *Scientific reports.*, 10(1): 1-11.
- Yousra M, Sarwar S, Hassan M M, Khan, M Z, khaliq, A. Ahmad S. and S.S. Shah. 2019. Comparative efficacy of different zinc sources for fertilization of maize (*Zea mays* L.) on alkaline calcareous soil. *Pakistan J. of Agric. Res.*, 32: 480-485.
- Zachara, J. M., Kittrick, J. A., and J.B. Harsh. 1988. The mechanism of Zn²⁺ adsorption on calcite. *Geochimica et Cosmochimica Acta.*, 52(9): 2281-2291.
- Zajaczkowska, A., Korzeniowska, J., and U. Sienkiewicz-Cholewa. 2020. Effect of soil and foliar silicon application on the reduction of zinc toxicity in wheat. *Agric.*, 10(11): 522.