**Annals of Plant and Soil Research 27(3): 319-326 (2025)**
https://doi.org/10.47815/apsr.2025.10471

# Impact of split application of vermicompost and zinc fertilization on soil properties and zinc fractions in fenugreek (*Trigonella Foenum-Graecum* L.)

**PREETI CHAHAR[1], GAJANAND JAT[2] AND KIRAN DOODHAWAL[2]**

[1]Department of Soil Science & Agricultural Chemistry, Rajasthan College of Agriculture, MPUAT, Udaipur

Received: June, 2025; Revised accepted: August, 2025

## ABSTRACT

*A field experiment was conducted during rabi season of 2021-22 at Rajasthan College of Agriculture, Udaipur (Rajasthan), to study the response of split application of vermicompost and zinc fertilization on soil physio-chemical properties and zinc fractions in fenugreek (Trigonella foenum-graecum L.) crop under Typic Haplustepts soil of sub-humid southern plain of Rajasthan. The treatments comprised of four treatments of split application of vermicompost (Control, 100% at sowing, 75% at sowing + 25% at 30 DAS and 50% at sowing + 50% at 30 DAS) and four levels of zinc application (Control, 5 kg $ZnSO_4$, 10 kg $ZnSO_4$ and 15 kg $ZnSO_4$ $ha^{-1}$). The experiment was laid out in a factorial randomized block design with three replications. Results revealed that the soil available nitrogen, phosphorus, potassium and zinc as well as the water soluble + exchangeable zinc, adsorbed zinc, organically bounded zinc, occluded zinc, residual zinc and total zinc was significantly increased upto 75% at sowing + 25% at 30 DAS which was found statistically at par with 50% at sowing + 50% at 30 DAS . However, the increasing level of zinc upto 10 kg $ZnSO_4$ $ha^{-1}$ enhanced the soil available nitrogen and potassium after harvest of crop which was found statistically at par with 15 kg $ZnSO_4$ $ha^{-1}$. The application of zinc decreased the available phosphorus content in soil at harvest of fenugreek. In addition to this, the application of zinc increased the soil available zinc and chemical fractions of zinc (water soluble + exchangeable zinc, adsorbed zinc, organically bounded zinc, occluded zinc, residual zinc and total zinc) in order 15 kg $ZnSO_4$ $ha^{-1}$>10 kg $ZnSO_4$ $ha^{-1}$ >5 kg $ZnSO_4$ $ha^{-1}$ >Control. Based on results, split application of vermicompost and zinc levels significantly increased available nitrogen, phosphorus, potassium and DTPA-extractable-Zn, water soluble + exchangeable zinc, adsorbed zinc, organically bounded zinc, occluded zinc, residual zinc and total zinc content in soil after harvest of crop.*

**Key words:** Fenugreek, soil properties, vermicompost, zinc, zinc fractions

## INTRODUCTION

Fenugreek (*Trigonella foenum graecum* L.) popularly known by its vernacular name "Methi" is an important condiment crop grown in northern India during *rabi* season. It occupied prime place amongst the seed spices grown in northern India particularly in Rajasthan. In India, it occupies 117294 hectares with the annual production of 185170 tonnes. The average productivity of seed is 1600 kg $ha^{-1}$. Madhya Pradesh, Rajasthan, Gujarat, Uttar Pradesh, Maharashtra and Punjab are leading states of fenugreek production in India. In Rajasthan, the crop is grown on 55000 hectares with an annual production of 70000 tonnes. The average productivity is 1273 kg $ha^{-1}$ (FAI, 2023-24). Vermicompost is being used as a soil conditioner, as it contains organic matter, plethora of microflora, macro and micronutrients, which helps in improving the nutrient status, physico-chemical and biological properties of soil. Manna and Ganguly (2000) reported the role of compost enriched with rock phosphate and pyrite in increasing the soil organic matter, soil microbial biomass, soil basal respiration, enzyme activity over sole application of mineral fertilizer thus, perking up the soil quality. Likewise, incorporation of compost also reduced the bulk density, improved the moisture retention of the sandy soil and simultaneously increased the yield of crop (Mylavarpu and Zinati, 2009). Enriched composts or composts besides supplying plant nutrients, add sufficient amount of organic matter to the soil, which helps in improving the physico-chemical properties of the soil (Das *et al.,* 2015).

Micronutrients are essential for crop production and their deficiency affects growth and metabolism especially during reproductive phase of the plant and also in animals and human beings. Among the micronutrients, zinc deficiency in both the plant and soil has been reported across the world (Alloway, 2008).

[2]*Department of Soil Science & Agricultural Chemistry, SKN College of Agriculture, Jobner*
**Corresponding Author Email: gajanand.soil@gmail.com*

Essentiality of zinc in the plant was first established by Maze (1915) in maize and subsequently in barley and sunflower (Sommer and Lipman, 1926). Cakmak (2008) reported that zinc deficiency may inhibit the activities of a number of antioxidant enzymes causing damage to the membrane lipids, proteins and nucleic acids. Shukla *et al.* (2021) reported that 36.5, 23.2, 13, 12.8, 7.1 and 4.2% soils of India are deficient in zinc, boron, molybdenum, iron, manganese and copper, respectively. Zinc is one of the essential micronutrients and plays an important role in various enzymatic and physiological activities of the plant. It is also essential for photosynthesis and nitrogen metabolism and important for the stability of cytoplasmic ribosome's, cell division, as co factor to enzymes like dehydrogenase, proteinase and peptidase in the synthesis of tryptophan, a component of some proteins and a compound needed for production of growth hormones (auxin) such as indole acetic acid. Most of the soils of Rajasthan have been found deficient in zinc and assigned low availability of zinc in coarse textured soils with low organic carbon content (Singh and Singh, 1981). Therefore, if the soil is in short supply with respect to zinc, crop yields are further adversely affected. Hence, it becomes necessary to pay serious attention to the application and utilization of zinc. Distribution of various chemical pools of Zn depends upon several factors such as inherent ability of soil to maintain supply of the element, soil management practices and various physico-chemical properties of soil. Soil Zn may be (i) in soil solution as ionic or organically complexed species, (ii) on exchangeable sites of reactive soil components, (iii) complexed with organic matter, (iv) occluded in oxides and hydroxides of Al, Fe and Mn and (v) entrapped by the primary and secondary minerals. Dissimilar soil Zn pools differ in their solubility and thus availability to plants. When Zn is applied to soil from external sources to correct deficiency, it undergoes transformation to various chemical pools, the nature and magnitude of which, may however, differ across soils, depending on physico-chemical properties and the associated environmental conditions.

## MATERIALS AND METHODS

**Experimental site and soil:** The experiment was conducted during *rabi* season of 2021-22 at the Instructional Farm (Agronomy), Rajasthan College of Agriculture, Udaipur situated at an altitude of 579.5 metres above mean sea level and at $24^0 34'$ latitude and $73^0 42'$ longitude. The region falls under agro-climatic zone-IVa (Sub-humid Southern Plain and Aravalli Hills) of Rajasthan. Soil of the experiment was clay loam in texture, saline in reaction (8.26$\pm$0.16), normal in electrical conductivity (0.627$\pm$0.01dS $m^{-1}$), medium in organic carbon (0.628$\pm$0.01%), low in available N (269.45$\pm$5.45 kg $ha^{-1}$), P (17.01$\pm$0.32 kg $ha^{-1}$), high in available K (350.20$\pm$7.12 kg$ha^{-1}$) and low in available zinc (0.592$\pm$0.012 mg $kg^{-1}$).

**Experimental design and treatments:** The experiment was laid out in factorial randomized block and replicated thrice in the plot size of 4.0 m x 3.0 m (12 $m^2$).The consisting of four treatments of split application of vermicompost (Control, 100% at sowing, 75% at sowing + 25% at 30 DAS and 50% at sowing + 50% at 30 DAS) and four levels of zinc application (Control, 5 kg $ZnSO_4$, 10 kg $ZnSO_4$ and 15 kg $ZnSO_4$ $ha^{-1}$). The fenugreek var. Rmt-9 was sown in lines 60 cm apart. As per the treatments, the application of vermicompost @4 t $ha^{-1}$ applied in the field as per treatments mixed at the time of sowing and 30 days stage of crop. The recommended dose of nitrogen (40 kg $ha^{-1}$) was applied in two equal splits, the half as basal and the remaining half was top dressed at the time of first irrigation. The basal dose was applied through urea after adjusting the quantity supplied through diammonium phosphate. The whole quantity of phosphorus was applied (40 kg $ha^{-1}$) through diammonium phosphate.

**Observations recorded:** The pH and EC were analyzed using method given by Richards (1954). Organic carbon, available N, P, K, Zn and Fe were determine using stand method given by Walkley and Black (1934), Subbiah and Asija (1956), Olsen *et al.* (1954), Merwin and Peech (1951) and Lindsay and Norvell (1978), respectively.

**Chemical fractions:** Chemical fractions of zinc were analyzed according to the sequential procedure of Iyengar and Deb (1977) and Chandi and Takkar (1982).

| S. No. | Chemical pool studied | Extractant | Procedure details |
|---|---|---|---|
| A. | Water soluble plus exchangeable (Wsex-Zn) (mg kg$^{-1}$) | 1N $NH_4OAC$ (pH 7.0) | 5 g of soil in a 50 ml centrifuged tube was shaken with 20 ml of the extractant for two hours and centrifuged 15 minutes at 2500 rpm. |
| B | Adsorbed zinc (Ads-Zn) (mg kg$^{-1}$) | 0.005 M DTPA (pH 7.3) | The residue of step A was shaken with 20 ml of DTPA extractant for four hours and centrifuged. |
| C. | Zinc associated with organic matter (Oc-Zn) (mg kg$^{-1}$) | 30% $H_2O_2$ and 0.005 M DTPA (pH 7.3) | The residue of steps B in centrifuge tubes was allowed to react with 5 ml of 30 % $H_2O_2$ and placed on a hot water bath over night and the contents in the tube was maintained 75°C $\pm$ 2 °C. After the completion of reaction the soil was shaken with 20 ml of 0.005 M DTPA for two hours and centrifuged. |
| D. | Occluded zinc and Zn bounded by carbonates and other acid soluble minerals (Occ-Zn) (mg kg$^{-1}$) | 0.1 NHCl | The residue of step C was shaken with 20 ml 0.1 N HCl for one hour and centrifuged |
| E. | Residual zinc (Res-Zn) (mg kg$^{-1}$) | - | Total zinc minus the sum of steps A B C and D |
| F. | Total zinc (T-Zn) (mg kg$^{-1}$) | - | 0.5 g of soil with a mixture of 10 ml of hydrofluoric acid, 3 to 6 drops of sulphuric acid and 5 ml of perchloric acid in Teflon beakers and analyzed by AAS (Page *et al.,* 1982). |

**Statistical analysis:** The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique as outlined by Panse and Sukhatme (1985) for a factorial randomized block design. The results are presented at 5% level of significance (P=0.05).

## RESULTS AND DISCUSSION

### Soil properties

**Effect of vermicompost:** Data given in Table 1 indicated that the split application of vermicompost significantly decreased the pH and electrical conductivity while increased the organic carbon, available nitrogen, phosphorus, potassium and zinc in soil after harvest of fenugreek crop over control. The lowest pH (8.15) and electrical conductivity (0.571 dSm$^{-1}$) was recorded under the split application of vermicompost @50% at sowing + 50% at 30 DAS ($VC_3$) and highest under control ($VC_0$). Whereas the maximum soil organic carbon (0.753%) was found with the split application of vermicompost @50% at sowing + 50% at 30 DAS ($VC_3$) and minimum under control. The decrease in pH and electrical conductivity of soil with the split application of vermicompost is due to the fact that production of organic acids on decomposition of organic matter and improvement in soil aggregation might have resulted in to lowering of soil pH and electrical conductivity (Nagar *et al.,* 2016). The significantly increased in soil organic carbon under vermicompost amended plots might be due to direct result of the organic fertilizer used with greater nutrient contents and organic matter in it. Additionally, larger root biomass resulting from the application of organic fertilizers added more root exudates and raised the soil organic carbon content (Sharma *et al.,* 2017). Similarly Sharma *et al.* (2016) observed comparable findings of enhanced soil organic carbon (2.3%) in acidic Inceptisols when FYM and vermicompost were applied in wheat cultivation.

The maximum available nitrogen (335.29 kg ha$^{-1}$), phosphorus (21.55 kg ha$^{-1}$), potassium (425.06 kg ha$^{-1}$) and zinc (0.794 mg kg$^{-1}$) were found with the split application of vermicompost @50% at sowing + 50% at 30 DAS ($VC_3$) and minimum under control (Table 1). However, the difference between $VC_3$ (50% at sowing + 50% at 30 DAS) and $VC_2$ (75% at sowing + 25% at 30 DAS) were non-significant for available nitrogen phosphorus, potassium and zinc in soil. The split application of vermicompost @ 50% at sowing + 50% at 30 DAS ($VC_3$) increased the available N, P, K and Zn to the extent of 23.44%, 15.18%, 20.94% and 33.68% over control, respectively. This might be due the addition of vermicompost, the total and available nutrient status of soil increased considerably due to mineralization of native as well as applied nutrients through organics (Roy *et al.,* 2010). The significant nutritional breakdown in vermicompost enhance multification of soil microbes which promotes the release of macro and micro nutrients in soil (Kumawat and Yadav, 2013). The microbial decomposition of added vermicompost in continuous crops creates acidifying environment and decreases soil pH, thus favours nutrient solubilization (Manivannan *et al.,* 2009). The increased availability of nutrients is also due to the formation of organic chelates of higher stability with organic legends, which have lower susceptibility to adsorption, fixation and precipitation in soil (Biswas, 2011). These results were supported by Zhao *et al.* (2021) who found that organic amendments improve soil available nutrients.

Table 1: Effect of split application of vermicompost and zinc fertilization on available pH, EC, organic carbon, available N, P, K and Zn in soil after harvest of fenugreek

| Treatments | pH | EC ($dSm^{-1}$) | Org. carbon (%) | Avail. N (kg $ha^{-1}$) | Avail. P (kg $ha^{-1}$) | Avail. K (kg $ha^{-1}$) | Avail. Zn (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| Split application of vermicompost | | | | | | | |
| Control ($VC_0$) | 8.29 | 0.635 | 0.631 | 271.63 | 18.71 | 351.47 | 0.594 |
| 100% at sowing ($VC_1$) | 8.21 | 0.628 | 0.672 | 298.96 | 19.52 | 382.38 | 0.655 |
| 75% at sowing + 25% at 30 DAS ($VC_2$) | 8.19 | 0.591 | 0.709 | 322.59 | 21.24 | 412.54 | 0.776 |
| 50% at sowing + 50% at 30 DAS ($VC_3$) | 8.15 | 0.571 | 0.753 | 335.29 | 21.55 | 425.06 | 0.794 |
| S.Em± | 0.026 | 0.002 | 0.010 | 5.04 | 0.11 | 4.48 | 0.008 |
| CD (P=0.05) | 0.074 | 0.005 | 0.029 | 14.56 | 0.32 | 13.25 | 0.022 |
| Zinc levels (kg $ha^{-1}$) | | | | | | | |
| Control ($Zn_0$) | 8.26 | 0.578 | 0.669 | 270.29 | 20.95 | 351.59 | 0.598 |
| 5 kg $ZnSO_4$ $ha^{-1}$ ($Zn_1$) | 8.23 | 0.606 | 0.695 | 298.95 | 20.76 | 382.64 | 0.638 |
| 10 kg $ZnSO_4$ $ha^{-1}$ ($Zn_2$) | 8.18 | 0.616 | 0.700 | 325.03 | 19.93 | 412.01 | 0.771 |
| 15 kg $ZnSO_4$ $ha^{-1}$ ($Zn_3$) | 8.17 | 0.625 | 0.702 | 334.21 | 19.39 | 425.22 | 0.812 |
| S.Em± | 0.026 | 0.002 | 0.010 | 5.04 | 0.11 | 4.48 | 0.008 |
| CD (P=0.05) | NS | 0.005 | NS | 14.56 | 0.32 | 13.25 | 0.022 |

**Effect of zinc application:** The application of zinc significantly enhanced the electrical conductivity over control. Whereas, Zn application showed non-significant effect on pH and organic carbon in soil after harvest of fenugreek (Table 1). The maximum value of electrical conductivity (0.625 $dSm^{-1}$) in soil was observed under the treatment of $Zn_3$ (15 kg $ZnSO_4$ $ha^{-1}$) and minimum value of electrical conductivity (0.578 $dSm^{-1}$) in soil was observed with the control ($Zn_0$). The increase in soil EC might be due to the direct correlation of EC and nutrients concentration in soil (Othaman *et al.,* 2020). The pH and organic carbon of soil remained unaffected even the use of zinc fertilizer due to inherent buffering capacity of the soil would resist small changes in soil reaction.

The application of zinc significantly enhanced the soil available nitrogen, potassium and zinc while decreased the soil available phosphorus over control (Table 1). The maximum soil available nitrogen (334.21 kg $ha^{-1}$), potassium (425.22 kg $ha^{-1}$) and zinc (0.812 mg $kg^{-1}$) were observed under Zn@15 kg $ZnSO_4$ $ha^{-1}$ ($Zn_3$) and minimum under control. The soil available nitrogen and potassium were increased significantly up to Zn@10 kg $ZnSO_4$ $ha^{-1}$ ($Zn_2$) which was found to be statistically at par with Zn@15 kg $ZnSO_4$ $ha^{-1}$ ($Zn_3$). The increased in N might be due to the increased enzymatic activity and the organic recycling of the plant nutrients in response to available zinc supply to plants and showed the importance of zinc application for nitrogen availability (Khan *et al.,* 2002). The increase in K could be due to the positive interaction of K and Zn (Adekiya *et al.,* 2018; Alloway, 2004). The experimental soil being low in available zinc might have resulted in increased available zinc with the increasing level of zinc application. There could be a 'Priming effect' which possibly caused solubilization of native zinc with increase in the rate of zinc application (Meena *et al.,* 2021). The maximum value of available phosphorus content in soil was obtained under control (20.95 kg $ha^{-1}$) and the minimum with application of Zn@15 kg $ZnSO_4$ $ha^{-1}$ (19.39 kg $ha^{-1}$). The cause behind this can be ascribed to antagonistic effect of zinc on availability of phosphorus, due to formation of insoluble zinc phosphate at higher concentration of zinc which reduces the availability of phosphorus. Such finding was also reported by Jat *et al.* (2015), Todawat *et al.* (2017) and Dhayal (2021).

## Zinc fractions

**Effect of vermicompost:** Data given in Table 2 indicated that the split application of vermicompost significantly enhanced the water soluble + exchangeable zinc (Wsex-Zn), adsorbed zinc (Ads-Zn), organically bounded zinc (Oc-Zn), occluded zinc (Occ-Zn), residual zinc (Res-Zn) and total zinc (T-Zn) content in soil after harvest of fenugreek over control. The maximum content of water soluble + exchangeable zinc (0.753 mg $kg^{-1}$), adsorbed zinc (4.41 mg $kg^{-1}$), organically bounded zinc (25.31 mg $kg^{-1}$), occluded zinc (14.45 mg $kg^{-1}$), residual zinc (33.23 mg $kg^{-1}$) and total zinc (78.15 mg $kg^{-1}$) and minimum under control. However increased significantly up to split application of vermicompost @75% at sowing + 25% at 30 DAS which was found to be statistically at par with split application of vermicompost @ 50% at sowing + 50% at 30 DAS. The lower value of zinc fractions in untreated plot might be due to low organic matter content and relatively higher soil pH. The formation of metallo-organic complexes with legends, mineralization and solubilization from the organic source might also be the reason for increased concentration in zinc fractions as in Wsex-Zn, Ads-Zn, Oc-Zn, Occ-Zn, Res-Zn and T-Zn. The formation of stable complexes of Zn with phenolic, hydroxy, carboxylic and amino groups rich in organic manure was reported by Yadav and Jha (1988) and these might keep the zinc in labile pool. This may also be ascribed to its high biodegradability which in turn results higher rate of mineralization of native as well as applied zinc in addition to its own zinc content which increased the concentration in zinc pool of soil (Panday *et al.,* 2018). Tabassum *et al.* (2014) reported increase in all chemical fractions of Zn with the application of organic manures in Vertisols of Jabalpur. Similar results were also reported by Karimi *et al.* (2019).

Table 2: Effect of split application of vermicompost and zinc fertilization on zinc fractions in soil after harvest of crop

| Treatments | Water soluble + exchangeable zinc (mg $kg^{-1}$) | Adsorbed zinc (mg $kg^{-1}$) | Organically bounded Zinc (mg $kg^{-1}$) | Occluded zinc (mg $kg^{-1}$) | Residual zinc (mg $kg^{-1}$) | Total zinc (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|
| Split application of vermicompost | | | | | | |
| Control ($VC_0$) | 0.715 | 4.14 | 23.37 | 13.65 | 31.29 | 73.17 |
| 100% at sowing ($VC_1$) | 0.734 | 4.28 | 24.57 | 14.05 | 32.50 | 76.13 |
| 75% at sowing+25% at 30 DAS ($VC_2$) | 0.748 | 4.37 | 25.09 | 14.33 | 33.02 | 77.57 |
| 50% at sowing+50% at 30 DAS ($VC_3$) | 0.753 | 4.41 | 25.31 | 14.45 | 33.23 | 78.15 |
| S.Em± | 0.004 | 0.03 | 0.12 | 0.07 | 0.12 | 0.34 |
| CD (P=0.05) | 0.010 | 0.07 | 0.35 | 0.20 | 0.35 | 0.97 |
| Zinc levels (kg $ha^{-1}$) | | | | | | |
| Control ($Zn_0$) | 0.714 | 4.14 | 23.35 | 13.62 | 31.27 | 73.10 |
| 5 kg $ZnSO_4$ $ha^{-1}$ ($Zn_1$) | 0.733 | 4.27 | 24.44 | 14.03 | 32.37 | 75.85 |
| 10 kg $ZnSO_4$ $ha^{-1}$ ($Zn_2$) | 0.746 | 4.36 | 25.04 | 14.30 | 32.97 | 77.41 |
| 15 kg $ZnSO_4$ $ha^{-1}$ ($Zn_3$) | 0.757 | 4.44 | 25.51 | 14.53 | 33.44 | 78.67 |
| S.Em± | 0.004 | 0.03 | 0.12 | 0.07 | 0.12 | 0.34 |
| CD (P=0.05) | 0.010 | 0.07 | 0.35 | 0.20 | 0.35 | 0.97 |

**Effect of zinc application:** The application of zinc significantly increased the water soluble + exchangeable zinc (Wsex-Zn), adsorbed zinc (Ads-Zn), organically bounded zinc (Oc-Zn), occluded zinc (Occ-Zn), residual zinc (Res-Zn) and total zinc (T-Zn) content in soil after harvest of fenugreek over control. The maximum content of water soluble + exchangeable zinc (0.757 mg $kg^{-1}$), adsorbed zinc (4.44 mg $kg^{-1}$), organically bounded zinc (25.51 mg $kg^{-1}$), occluded zinc (14.53 mg $kg^{-1}$), residual zinc (33.44 mg $kg^{-1}$) and total zinc (78.67 mg $kg^{-1}$) and minimum under control (Table 2). Maximum portion of applied Zn was present in the form of residual Zn (Res-Zn) followed by organically bound Zn (Oc-Zn), occluded Zn (Occ-Zn), adsorbed Zn (Ads-

Zn) and water soluble + exchangeable Zn (Wsex-Zn). Results showed that Res-Zn fraction contributed the most to the Total-Zn and depicts the extent of Zn accumulation in the soil. This shows that the majority of the applied Zn was converted into this Zn pool, which is the Zn fraction that is least available to the plants for uptake. This explains the potential cause of zinc deficiency in the experimental soil despite greater Total-Zn fraction concentrations (Butail *et al.,* 2022). The higher value of Ads-Zn had possibly resulted from the dissolution of some precipitated Zn fractions of applied Zn. In general, bulk of the applied Zn entered into the residual Zn pool which could be attributed to the fact that the soil adsorbs and retains most of the applied Zn in non-releasable form. The increased in organically bound Zn might be due to the fact that high yielding plots produce more crop biomass (including crop wastes and root biomass), which raises soil organic carbon and promotes the complexation and chemisorption of zinc to organic ligands (Sharad and Verma, 2001, Shambhavi *et al.,* 2020). The total Zn content increased with progressive rise in Zn levels upto 15 kg $ZnSO_4$ $ha^{-1}$. Possibly higher solubility, diffusion and mobility of the applied inorganic zinc fertilizer might be the reason leading to increased Zn status of soil. Similarly, increased in zinc fractions due to zinc fertilization reported by Verma *et al.* (2022).

## CONCLUSION

On the basis of experimental finding, it can be concluded that the split application of vermicompost @50% at sowing + 50% at 30 DAS and 15 kg $ZnSO_4$ $ha^{-1}$ significantly increased the available nitrogen, phosphorus, potassium and zinc as well as zinc fractions (water soluble + exchangeable zinc, adsorbed zinc, organically bounded zinc, occluded zinc, residual zinc and total zinc) in fenugreek on a Zn deficient Typic Haplustepts soil.

## REFERENCES


Adekiya, A.O., Aboyeji, C.M., Agbede, T.M., Dunsin, O. and Adebiyi, O. T. V. (2018) Effect of $ZnSO_4$ fertilizer on soil chemical properties, performance and proximate quality of sweet potato in derived savanna ecology of Nigeria. *Open Agriculture*, ***3***(1), 644-651.

Alloway, B.J. (2004) Zinc in soils and crop nutrition. 1st edn, International Zinc Association (IZA), Brussels, Belgium, 128.

Alloway, B. J. (2008) Zinc in soils and crop nutrition, 2nd edition. IZA Brussels, Belgium and IFA, Paris, France.

Biswas, D. R. (2011) Nutrient recycling potential of rock phosphate and waste mica enriched compost on crop productivity and changes in soil fertility under potato–soybean cropping sequence in an Inceptisol of Indo-Gangetic Plains of India. *Nutrient Cycling in Agro-ecosystems*, ***89***, 15-30.

Butail, N. P., Kumar, P., Shukla, A. K., Behera, S. K., Sharma, M., Kumar, P. and Green, A. (2022) Zinc dynamics and yield sustainability in relation to Zn application under maize-wheat cropping on Typic Hapludalfs. *Field Crops Research*, ***283***, 108525.

Cakmak, I. (2008) Zinc deficiency in wheat in Turkey. In: micronutrients deficiencies in global crop production. Ed. B. J. Alloway. 181-200, New York: Springer.

Chandi, K. S. and Takkar, P. N. (1982) Effects of agricultural cropping systems on micronutrients transformation: I. Zinc. *Plant and Soil*, ***69***, 423-436.

Das, T. Debnath, P. Satpute, P. B. and Bandyopadhyay, S. (2015) Effect of phosphorus enriched vermicompost on growth and yield of groundnut (*Arachis hypogaea* L.) influenced by soil phosphorus use efficiency. *Indian Journal of Science and Technology*, ***8***(11):2-9.

Dhayal, S. (2021) Effect of nutrient enriched compost and zinc application on zinc fractions and productivity of Maize (*Zea mays* L.). M. Sc. (Ag.) *Thesis*, Maharana Pratap Agricultural University and Technology, Udaipur.

FAI. (2023-24) Fertiliser Statistics. The Fertiliser Association of India, New Delhi.

Jat, G., Sharma, K. K. and Jat, N. K. (2015) Effect of FYM and mineral nutrients on physio-chemical properties of soil under mustard in western arid zone of India. *Annals of Plant and Soil Research*, ***14***:

167-170.

Iyengar, B.R.V. and Deb, D.L. (1977) Contribution of soil zinc fractions to plant uptake and fate of zinc applied to the soil. *Journal of the Indian Society of Soil Science*, ***25***(4), 426-432.

Karimi, A., Moezzi, A., Chorom, M. and Enayatizamir, N. (2019) Chemical fractions and availability of Zn in a calcareous soil in response to biochar amendments. *Journal of Soil Science and Plant Nutrition*, ***19***, 851-864.

Khan, M.U., Qasim, M. and Jamil, M. (2002) Effect of different levels of zinc on the extractable zinc content of soil and chemical composition of rice. *Asian Journal of Plant Sciences*, **1***:* 20-21*.*

Kumawat, S. R. and Yadav, B. L. (2013) Sodicity tolerance of fenugreek (*Trigonella foenum graecum* L.) as influenced by application of zinc and vermicompost. *Legume Research-An International Journal*, ***36***(4), 312-317.

Lindsay, W.L. and Norvell, W.A. (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*, ***42*****,** 421-442.

Manivannan, S., Balamurugan, M., Parthasarathi, K., Gunasekaran, G. and Ranganathan, L.S. (2009) Effect of vermicompost on soil fertility and crop productivity Beans (*Phaseolus vulgaris*). *Journal of Environmental Biology*, ***30***, 275–281.

Manna, M.C. and Ganguly, T.K. (2000) Rockphosphate and pyrite in compost technology: their role in improving crop productivity and soil quality. *Fertiliser News*, ***45***(7): 41-48.

Meena, M., Jat, G., Meena, R.H., Sharma, S.K., Choudhary, R., Yadav, S.K. and Jat, H. (2021) Effect of phospho enriched compost and zinc on soil properties and productivity of blackgram (*Vigna mungo*). *Indian Journal of Agricultural Sciences,* ***91***(9), 1333–1336.

Merwin, H.D. and Peech, M. (1951) Exchangeability of soil potassium in the sand, silt, and clay fractions as influenced by the nature of the complementary exchangeable cation. *Soil Science Society of America Journal*, ***15***, 125-128.

Mylavarpu, R.S. and Zinati, G.M. (2009) Improvement of soil properties using compost for optimum Parsely production in sandy soil. *Scientia Horticulturae,* ***120***(3): 426-430.

Nagar, R.K., Goud, V.V., Kumar, R. and Kumar, R. (2016) Effect of organic manures and crop residue management on physical, chemical and biological properties of soil under pigeonpea based intercropping system. *International Journal of Farm Sciences*, ***6***(1), 101-113.

Olsen, S.R., Cole, C.V., Frank, S.W. and Dean, L.A. (1954) Estimation of available phosphorus by extraction with sodium bicarbonate, United States Development of Agriculture Circular number, 939.

Othaman, N.C., Isa, M.M., Ismail, R.C., Ahmad, M.I. and Hui, C.K. (2020) Factors that affect soil electrical conductivity (EC) based system for smart farming application. In *AIP Conference Proceedings,* ***2203***: (1) 020055.

Page, A.L., Miller, R.H. and Keeny, D.R. (1982) (Ed.) Methods of soil analysis part 2, American Society of Agronomy, Madison U.S.A., 491.

Pandey, A.K., Kumar, V., Prasad, J. and Prasad, R.K. (2018) Effect of organic and inorganic fertilizers on zinc fractions and their contribution to zinc uptake under rice-wheat system. *Current Journal of Applied Science and Technology*, ***31***(1), 1-7.

Panse, V.G. and P.V. Sukhatme. (1985) Statistical Methods for Agricultural Workers. ICAR, New Delhi.

Richards, L.A. (1954) Diagnosis and Improvement of Saline- alkali Soils. Agriculture Handbook No. 60, USDA, Washington.

Roy, S., Arunachalam, K., Dutta, B.K. and Arunachalam, A. (2010) Effect of organic amendments of soil on growth and productivity of three common crops viz. *Zea mays, Phaseolus vulgaris* and *Abelmoschus esculentus*. *Applied Soil Ecology,* ***45***(2), 78-84.

Shambhavi, S., Kumar, R., Padbhushan, R., Verma, G., Sharma, S.P., Sharma, S.K. and Sharma, R. P. (2020) Dynamics of zinc under long-term application of chemical fertilizers and amendments by maize–wheat cropping sequence in Typic Hapludalfs. *Soil Use and Management*, ***36***(3), 507-523.

Sharad, N. and Verma, T. S. (2001) Improvement in Soil Productivity with Long-term lantana (*Lantana camara* L.) additions in Rice-Wheat Cropping–I. Effects on Some Soil Properties and Zinc Fractions. *Journal of the Indian Society of Soil Science*, ***49***(3), 462-466.

Sharma, J.K., Jat, G., Meena, R.H., Purohit, H.S. and Choudhary, R.S. (2017) Effect of vermicompost and nutrients application on soil properties, yield and uptake and quality of Indian mustard. *Annals of Plant and Soil Research*, ***19***(1):17-22.

Sharma, B., Buragohain, S., Nath, D. J. and Gogoi, N. (2016) Temporal responses of soil biological characteristics to organic inputs and mineral fertilizers under wheat cultivation in Inceptisol. *Archives of Agronomy and Soil Science*, ***63***(1), 35-47.

Shukla, A.K., Behera, S.K., Prakash, C., Patra, A.K., Rao, C.S., Chaudhari, S.K. and Green, A. (2021) Assessing multi-micronutrients deficiency in agricultural soils of India. *Sustainability*, ***13***(16), 9136.

Singh, M. and Singh, K.S. (1981) Zinc and copper status of soil of Rajasthan. *Annals of Arid Zone, **20***: 77.

Sommer, A.L. and Lipman, C.B. (1926) Evidence on the indispensable nature of zinc and boron for higher green plants. *Plant Physiology*, ***1***:231-249.

Subbaiah, B.V. and Asija, G.L. (1956) A rapid method for estimation of available N in soil. *Current Science*, ***25***, 259-260.

Tabassum, S., Jeet, S., Kumar, R., Dev, C.M. and Kumar, P. (2014) Effect of organic manure and zinc fertilization on zinc transformation and bio-fortification of crops in vertisols of central India. *Journal of Agricultural Science*, ***6***(8), 221.

Todawat, A. Sharma, S.R., Lakharan, H. and Hemraj (2017) Effect of vermicompost and zinc on growth, yield attributes and yields of Greengram (*Vigna radiata* L.) Under semi-arid region of Rajasthan. *International Journal of Current Microbiology and Applied Science, **6***(9), 175-180.

Verma, D., Meena, R.H., Sukhwal, A., Jat, G., Meena, S.C., Upadhyay, S.K. and Jain, D. (2022) Effect of ZSB with graded levels of Zinc fertilizer on yield and Zinc uptake under maize cultivation. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 1-7.

Walkley, A.J. and Black, I.A. (1934) Estimation of soil organic carbon by chromic acid titration method. *Soil Science*, ***37***, 29-38.

Yadav, K. and Jha, K.K. (1988) Effect of poultry manure and sewage sludge on the humification and functional groups of humic substances. *Journal of the Indian Society of Soil Science, **36***, 439-449.

Zhao, Y., Chen, Y., Dai, H., Cui, J., Wang, L. and Sui, P. (2021) Effects of organic amendments on the improvement of soil nutrients and crop yield in sandy soils during a 4-year field experiment in Huang-Huai-Hai Plain, Northern China. *Agronomy*, 11(1), 157.