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RESEARCH ARTICLE

# Influence of household waste based vermicompost and fertilizer on micronutrient mineralization in calcareous soil

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## Abstract

To address the challenge of increasing household waste generated by global population growth and urbanization, particularly in developing nations such as India, it is imperative to implement effective waste management practices. One such approach gaining recognition is residue recycling, encompassing composting and vermicomposting of organic portion of household waste. Taking this into consideration, an incubation study was undertaken during *Kharif* 2018 at RPCAU, Pusa, to examine the mineralization of vermicompost in calcareous sandy loam soil at five distinct stages, which match the critical growth stages of the rice crop. The experiment was conducted in Completely Randomized design (3 factors) replicated thrice. Four levels of vermicompost, along with three levels of chemical fertilizers, were used at field capacity in various combinations and alone. The content of available micronutrients (Fe, Mn, Cu and Zn) in soil increased significantly up to 65 DAI, then decreased for all treatments. The treatment combination involving the application of the highest dose of vermicompost (3.75 t $ha^{-1}$) along with the full recommended dose of fertilizer (RDF) was recorded as significantly superior. As, micronutrients are important for plant growth and health and need to be added to soil to replace what plants take up. Increasing the level of vermicompost application resulted in a significant increase in micronutrient content, whereas the different doses of chemical fertilizer did not exhibit a significant variation. Overall, the findings highlight the potential benefits of combining vermicompost and chemical fertilizer, particularly at higher vermicompost application rates, for enhancing micronutrient content in the soil.

**Keywords:** copper (Cu); *Eisenia fetida*; iron (Fe); manganese (Mn); vermicompost; zinc (Zn)

## Introduction

Unprecedented levels of urbanization, along with population growth, have resulted in a massive increase in consumption and the subsequent generation of waste, which is expected to increase further in the coming years. The world generates 2.01 billion tonnes of municipal solid waste annually and worldwide, waste generated per person per day averages 0.74 kg. Global waste is expected to grow to 3.40 billion tonnes by 2050 (1). According to a 2014 Planning Commission report, India generates about 65 million tonnes of waste annually and over 62 million tonnes (Mt) of it are municipal solid waste that includes 30 % to 55 % of biodegradable (organic) matter, 40 % to 55 % inert matter and 5 % to 15 % recyclables, etc (2). According to the CPCB's annual report on solid waste management (2020-21), the total quantity of solid waste generated in the country is 0.16 Mt per day and per capita solid waste generation has been 0.12 kg/day (3). These wastes are either dumped openly or landfilled in nearby sites, creating a negative impact on the environment and human health, as well as causing a severe problem of disposal. However, most of these wastes are potentially nutrient-rich and when improperly disposed of, a considerable amount of untapped nutrients locked in the waste is lost. Analysis conducted by the National Environmental Engineering Research Institute (2005) has revealed that, on average, domestic waste in India consists of approximately 0.64 % nitrogen, 0.67 % phosphorus and 0.68 % potassium, with a C:N ratio of 26 (4). Instead of disposing of the organic part of these wastes, it can be recuperated by a proper technique for the protection of the environment and the conversion of these potential sources of untapped nutrients into useful fertilizers for improving and sustaining soil fertility. To ensure hygienic waste management, it should be managed effectively, which can be achieved by composting and vermicomposting of farm, urban and agro-industrial waste. Composting, an aerobic microbial process, is widely recognized as the preferred method for transforming organic matter (5, 6). Among various methods of composting, vermicomposting is one of the best options for treating domestic household waste (7). Vermicompost typically exhibits higher levels of various essential mineral elements, such as nitrates, exchangeable phosphorus, soluble potassium, calcium, magnesium and micronutrients in readily available forms compared to the initial substrate (8). Consequently, vermicomposting significantly increases the concentration of nutrients in organic wastes (9).

Meeting the needs of a rapidly growing population and ensuring food security necessitates a significant increase in crop production. The advent of the Green Revolution in the 1960s brought about remarkable advancements in food grain production in India and worldwide through the use of high-yielding varieties, chemical fertilizers, pesticides and other modern agricultural practices. However, the long-term consequences of indiscriminate fertilizer use, combined with inadequate farming practices, have led to a decline in soil health and fertility. Extensive literature reports consistently emphasize that neither the use of organic manures alone nor reliance solely on chemical fertilizers can ensure sustainable yields; the exclusive use of chemical fertilizers ultimately leads to soil degradation. Plants require micronutrients in smaller quantities compared to macronutrients. As a result, micronutrient deficiencies are less frequent than macronutrient deficiencies, but they play a vital role in essential cellular processes. A lack of micronutrients can hinder plant growth, reduce yields and lower crop quality, ultimately impacting the health and productivity of both animals and humans. At present, micronutrient deficiencies in arable soils are a widespread global issue. The escalating costs of fertilizers and their adverse effects on soil properties have necessitated the incorporation of organic manures as a supplement to chemical fertilizers in crop production. Organic matter plays a pivotal role in enhancing soil fertility and sustaining long-term soil productivity. The significance of vermicompost as a source of humus and its profound impact on enhancing soil fertility and overall soil health has been firmly established in multiple studies (10-15).

The present investigation primarily aimed to understand the Fe, Mn, Cu and Zn mineralization patterns in soil following the application of household waste-based vermicompost alone or in combination with fertilizer.

## Materials and Methods

### Vermicompost production

In the present study, household waste used as a substrate for vermicomposting was sourced from the university's collection system, which gathered waste from 750 residential quarters and hostels within the Dr Rajendra Prasad Central Agricultural University (RPCAU), Pusa campus. At the same time, cow dung was collected from the livestock farm at the Vermicompost Production Unit, RPCAU, Pusa. For the experiment, household waste was combined with cow dung in a 50:50 ratio at 37 ˚C temperature and 65 % w/w moisture in a windrow of size 10 ft × 2 ft × 1.5 1.5 ft under shade. The substrate was enriched with the addition of rock phosphate (on a $P_2O_5$ basis @ 5 % w/w) and PSB (@500 g PSB carrier-based bio-fertilizer per ton of material). The Earthworm species used was *Eisenia fetida*, at 2 kg per ton of substrate. Characterization of the vermicompost was conducted before setting up the incubation experiment and the nutrient content of the vermicompost is presented in Table 1.

**Table 1.** Vermicompost nutrient content

| Sl. No. | Parameters | Value |
|---|---|---|
| 1. | Moisture content ( %) | 16.00 |
| 2. | Maximum water holding capacity ( %) | 20.70 |
| 3. | Bulk density (g $cm^{-3}$) | 0.80 |
| 4. | pH | 7.30 |
| 5. | EC ($dSm^{-1}$) | 0.51 |
| 6. | Total organic carbon (TOC) % | 34.40 |
| 7. | Total Nitrogen (TN) % | 2.40 |
| 8. | TOC/TN ratio | 14.60 |
| 9. | Total phosphorus ( %) | 1.34 |
| 10. | Total potassium ( %) | 1.79 |
| 11. | Total Fe (mg $kg^{-1}$) | 1395.11 |
| 12. | Total Cu (mg $kg^{-1}$) | 39.31 |
| 13. | Total Mn (mg $kg^{-1}$) | 364.60 |
| 14. | Total Zn (mg $kg^{-1}$) | 179.56 |

### Experimental design

An incubation experiment was carried out in the sandy loam soil of Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, during the Kharif season of 2018. The study followed a Completely Randomized Design (CRD) with three factors and was replicated three times. For study four levels of household waste based vermicompost (V) i.e., $V_0$: No manure, $V_1$: Vermicompost @ 1.25 t $ha^{-1}$, $V_2$: Vermicompost @ 2.5 t $ha^{-1}$, $V_3$: Vermicompost @ 3.75 t $ha^{-1}$and three levels of fertilizers (F) i.e., $F_0$: No. fertilizer, $F_1$: RDF, $F_2$: 50 % RDF were used at field capacity (19.47 %) in combinations and alone and observations were recorded at five different stages (S) which match with the critical growth stages of rice crop i.e. 0 day, 30 days after incubation (DAI), 65 DAI, 100 DAI and 120 DAI. The vermicompost and N (nitrogenous), P (phosphatic) and K (potassium) fertilizers were thoroughly mixed according to the requirements with 200 g of soil in each box, as per the treatments. The total number of boxes was 180. The field capacity of the soil was maintained throughout the incubation period.

### Soil analysis

In order to find out the micronutrient release pattern of vermicompost either alone or in presence of fertilizer in soil, the soil samples were collected from incubation boxes of each treatment and for all replications separately at five different stages of incubation i.e. at 0 day, 30 days after incubation (DAI), 65 DAI, 100 DAI and 120 DAI. Soil samples were air-dried in the shade and ground to pass through a 2 mm sieve. They were then kept in separate sampling bags and sent to the lab for analysis. The available iron (Fe), copper (Cu), zinc (Zn), manganese (Mn) was determined by atomic absorption spectrophotometer (AAS) after extracting the soil with DTPA based on the procedure (16).

The soil of experimental site belongs to order *Entisol*. It is characterized as Calciorthents which is sandy loam in texture with alkaline pH (8.06), low in available N (220 kg $ha^{-1}$) and P (17.80 kg ha-1). In comparison, medium in available K (146.5 kg $ha^{-1}$) and the data has been presented in Table 2 (14).

### Statistical analysis

All the data observed under the proposed investigation were analyzed statistically using a Factorial Completely Randomized Design, as described by (17). Statistical tools, such as Standard Error (SE), Analysis of Variance (ANOVA) and Correlation coefficient, were employed in the study. All the values for analysis were presented as the mean ± standard error (SEm). Analysis was also conducted online (http://14.139.232.166/opstat/default .asp) using analysis of variance technique (ANOVA) (18). The significance of the treatment mean was tested at a 5 % (P ≤ 0.05) level of probability.

**Table 2.** Physico-chemical properties of experimental soil (0-15 cm depth before starting of experiment)

| Sl. No. | Soil properties | Value |
|---|---|---|
| 1. | Textural class | Sandy loam |
| 2. | Sand ( %) | 55.5 |
| 3. | Silt ( %) | 35 |
| 4. | Clay ( %) | 9.5 |
| 5. | pH | 8.06 |
| 6. | EC (dS $m^{-1}$) | 0.21 |
| 7. | Total Organic Carbon ( %) | 0.98 |
| 8. | Available N (kg $ha^{-1}$) | 220 |
| 9. | Available $P_2O_5$ (kg $ha^{-1}$) | 17.80 |
| 10. | Available $K_2O$ (kg $ha^{-1}$) | 146.5 |
| 11. | Available Fe (mg $kg^{-1}$) | 6.90 |
| 12. | Available Cu (mg $kg^{-1}$) | 0.71 |
| 13. | Available Zn (mg $kg^{-1}$) | 0.74 |
| 14. | Available Mn (mg $kg^{-1}$) | 3.07 |

## Results and Discussion

### Available micronutrients

The results on contents of DTPA extractable micronutrients (mg $kg^{-1}$), as influenced by application of vermicompost at four doses (0, 1.25, 2.5 and 3.75 t $ha^{-1}$) either alone or in combinations with three fertilizers levels (0, RDF and 50 % RDF) at five stages of incubation i.e. 0, 30, 65, 100 and 120 DAI (days after incubation), have been shown in tables separately (Table 3-6). A critical analysis of the data indicated that the application of different doses of vermicompost and fertiliser significantly increased the DTPA extractable Fe, Mn, Cu and Zn content of the soil during the incubation period compared to the control. The levels of available Fe, Mn, Cu and Zn increased until the 65$^{th}$ day after incubation and subsequently declined.

### Iron

Irrespective of incubation stages, the increasing value of vermicompost led to a significant increase in the content of DTPA extractable Fe, which varied from 6.73 to 7.72 mg $kg^{-1}$. In contrast, the DTPA extractable Fe content did not vary significantly due to different levels of fertiliser dose (Table 3). Available Fe content increased significantly up to 65 DAI, followed by a decline, irrespective of the fertiliser level, which aligns with findings by Washimkar (1997) (19). The content of available Feduring starting of incubation ranged from 6.62 to 6.81 mg $kg^{-1}$, 6.76 to 8.22 mg $kg^{-1}$at 30 DAI, 6.83 to 8.69 mg $kg^{-1}$at 65 DAI, 6.77 to 7.71 mg $kg^{-1}$ at 100 DAI and 6.69 to 7.18 mg $kg^{-1}$ at 120 DAI. Additionally, irrespective of vermicompost doses, the content of available Fe, as influenced by different doses of fertiliser, did not vary significantly during the incubation period. The treatment receiving highest dose of vermicompost (3.75 t $ha^{-1}$) in combination with full dose of fertilizer recorded 5.23 %, 26.61 %, 35.08 %, 18.77 % and 10.46 % increase over control at 0, 30, 65, 100 and 120 days after incubation, respectively.

The interaction between vermicompost and chemical fertilizer did not yield significant variations. However, an increasing level of vermicompost resulted in a significant increase in the available Fe content of the soil at all observational stages during the incubation study, which is consistent with the findings of previous research (15, 20). The availability of Fe was observed to increase with the incubation period, which may be due to the complexation of Fe with active $CaCO_3$ present in calcareous soil, or may be due to the conversion of oxides as a result of microbial and chemical reduction and a decrease in pH (21, 22).

The available Fe content exhibited a significant increase with the application of vermicompost, reaching up to 3.75 t $ha^{-1}$. This consistent trend was observed across all time periods (0, 30, 65, 100 and 120 DAI), with the interaction effect between the incubation stage and vermicompost level being found to be significant.

**Table 3.** Effect of vermicompost and fertilizer on Fe mineralization

| Treatments | Total Fe (mg $kg^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Stages of observation | | | | | |
| | 0 DAI | 30 DAI | 60 DAI | 90 DAI | 120 DAI | Mean |
| $V_0F_0$ | 6.50 | 6.68 | 6.68 | 6.65 | 6.64 | 6.63 |
| $V_0F_1$ | 6.70 | 6.83 | 6.89 | 6.82 | 6.72 | 6.79 |
| $V_0F_2$ | 6.66 | 6.78 | 6.83 | 6.79 | 6.70 | 6.75 |
| $V_1F_0$ | 6.69 | 6.91 | 7.51 | 7.15 | 6.83 | 7.02 |
| $V_1F_1$ | 6.75 | 6.95 | 7.55 | 7.18 | 6.88 | 7.06 |
| $V_1F_2$ | 6.71 | 6.94 | 7.54 | 7.16 | 6.85 | 7.04 |
| $V_2F_0$ | 6.73 | 7.45 | 8.48 | 7.57 | 7.13 | 7.47 |
| $V_2F_1$ | 6.81 | 7.66 | 8.65 | 7.62 | 7.15 | 7.58 |
| $V_2F_2$ | 6.79 | 7.49 | 8.54 | 7.60 | 7.14 | 7.51 |
| $V_3F_0$ | 6.76 | 8.21 | 8.64 | 7.71 | 7.17 | 7.70 |
| $V_3F_1$ | 6.84 | 8.23 | 8.78 | 7.72 | 7.18 | 7.75 |
| $V_3F_2$ | 6.82 | 8.23 | 8.66 | 7.71 | 7.18 | 7.72 |
| Mean | 6.73 | 7.36 | 7.90 | 7.31 | 6.96 | |
| | CD (5 %) | SEm(±) | | | | |
| Stages (S) | 0.11 | 0.04 | | | | |
| Vermicompost (V) | 0.10 | 0.04 | | | | |
| S × V | 0.23 | 0.08 | | | | |
| Fertilizers (F) | NS | 0.03 | | | | |
| S × F | NS | 0.07 | | | | |
| V × F | NS | 0.06 | | | | |
| S × V × F | NS | 0.14 | | | | |

$V_0F_0$-No manure + no fertilizer, $V_0F_1$- No manure + RDF, $V_0F_2$: No manure + 50 % RDF, $V_1F_0$- Vermicompost (1.25 t $ha^{-1}$) + no fertilizer, $V_1F_1$- Vermicompost (1.25 t $ha^{-1}$) + RDF, $V_1F_2$- Vermicompost (1.25 t $ha^{-1}$) + 50 % RDF, $V_2F_0$- Vermicompost (2.50 t $ha^{-1}$) + no fertilizer, $V_2F_1$- Vermicompost (2.50 t $ha^{-1}$) + RDF, $V_2F_2$- Vermicompost (2.50 t $ha^{-1}$) + 50 % RDF, $V_3F_0$- Vermicompost (3.75 t $ha^{-1}$) + no fertilizer, $V_3F_1$- Vermicompost (3.75 t $ha^{-1}$) + RDF, $V_3F_2$- Vermicompost (3.75 t $ha^{-1}$) + 50 % RDF. CD (5 %) = Critical difference at 5 %, SEm(±) = Standard error of the mean.

**Table 4.** Effect of vermicompost and fertilizer on Cu mineralization

| Total Cu (mg kg$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|
| Treatments | Stages of observation | | | | | |
| | 0 DAI | 30 DAI | 60 DAI | 90 DAI | 120 DAI | Mean |
| $V_0F_0$ | 0.71 | 0.71 | 0.71 | 0.70 | 0.69 | 0.71 |
| $V_0F_1$ | 0.72 | 0.72 | 0.72 | 0.70 | 0.70 | 0.71 |
| $V_0F_2$ | 0.72 | 0.72 | 0.71 | 0.70 | 0.70 | 0.71 |
| $V_1F_0$ | 0.73 | 0.73 | 0.74 | 0.73 | 0.73 | 0.73 |
| $V_1F_1$ | 0.73 | 0.73 | 0.74 | 0.74 | 0.73 | 0.74 |
| $V_1F_2$ | 0.73 | 0.73 | 0.74 | 0.73 | 0.73 | 0.73 |
| $V_2F_0$ | 0.78 | 0.78 | 0.79 | 0.78 | 0.77 | 0.78 |
| $V_2F_1$ | 0.78 | 0.78 | 0.80 | 0.78 | 0.78 | 0.78 |
| $V_2F_2$ | 0.78 | 0.78 | 0.79 | 0.78 | 0.77 | 0.78 |
| $V_3F_0$ | 0.79 | 0.79 | 0.80 | 0.79 | 0.79 | 0.79 |
| $V_3F_1$ | 0.79 | 0.79 | 0.80 | 0.79 | 0.79 | 0.79 |
| $V_3F_2$ | 0.79 | 0.79 | 0.80 | 0.80 | 0.79 | 0.79 |
| Mean | 0.75 | 0.76 | 0.76 | 0.75 | 0.75 | |
| | CD (5 %) | SEm(±) | | | | |
| Stages (S) | NS | 0.004 | | | | |
| Vermicompost (V) | 0.010 | 0.004 | | | | |
| S × V | NS | 0.008 | | | | |
| Fertilizers (F) | NS | 0.003 | | | | |
| S × F | NS | 0.007 | | | | |
| V × F | NS | 0.006 | | | | |
| S × V × F | NS | 0.014 | | | | |

$V_0F_0$-No manure + no fertilizer, $V_0F_1$- No manure + RDF, $V_0F_2$: No manure + 50 % RDF, $V_1F_0$- Vermicompost (1.25 t ha$^{-1}$) + no fertilizer, $V_1F_1$- Vermicompost (1.25 t ha$^{-1}$) + RDF, $V_1F_2$- Vermicompost (1.25 t ha$^{-1}$) + 50 % RDF, $V_2F_0$- Vermicompost (2.50 t ha$^{-1}$) + no fertilizer, $V_2F_1$- Vermicompost (2.50 t ha$^{-1}$) + RDF, $V_2F_2$- Vermicompost (2.50 t ha$^{-1}$) + 50 % RDF, $V_3F_0$- Vermicompost (3.75 t ha$^{-1}$) + no fertilizer, $V_3F_1$- Vermicompost (3.75 t ha$^{-1}$) + RDF, $V_3F_2$- Vermicompost (3.75 t ha$^{-1}$) + 50 % RDF. CD (5 %) = Critical difference at 5 %, SEm(±) = Standard error of the mean.

**Table 5.** Effect of vermicompost and fertilizer on Zn mineralization

| Total Zn (mg kg$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|
| Treatments | Stages of observation | | | | | |
| | 0 DAI | 30 DAI | 60 DAI | 90 DAI | 120 DAI | Mean |
| $V_0F_0$ | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| $V_0F_1$ | 0.74 | 0.75 | 0.74 | 0.74 | 0.74 | 0.74 |
| $V_0F_2$ | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| $V_1F_0$ | 0.74 | 0.75 | 0.75 | 0.74 | 0.74 | 0.74 |
| $V_1F_1$ | 0.74 | 0.75 | 0.75 | 0.74 | 0.74 | 0.75 |
| $V_1F_2$ | 0.74 | 0.75 | 0.75 | 0.74 | 0.74 | 0.75 |
| $V_2F_0$ | 0.76 | 0.77 | 0.77 | 0.76 | 0.76 | 0.76 |
| $V_2F_1$ | 0.76 | 0.78 | 0.78 | 0.77 | 0.77 | 0.77 |
| $V_2F_2$ | 0.76 | 0.78 | 0.78 | 0.77 | 0.77 | 0.77 |
| $V_3F_0$ | 0.83 | 0.85 | 0.86 | 0.84 | 0.84 | 0.85 |
| $V_3F_1$ | 0.84 | 0.86 | 0.86 | 0.85 | 0.84 | 0.85 |
| $V_3F_2$ | 0.84 | 0.86 | 0.86 | 0.85 | 0.84 | 0.85 |
| Mean | 0.77 | 0.78 | 0.78 | 0.78 | 0.77 | |
| | CD (5 %) | SEm(±) | | | | |
| Stages (S) | NS | 0.004 | | | | |
| Vermicompost (V) | 0.011 | 0.004 | | | | |
| S × V | NS | 0.009 | | | | |
| Fertilizers (F) | NS | 0.003 | | | | |
| S × F | NS | 0.008 | | | | |
| V × F | NS | 0.007 | | | | |
| S × V × F | NS | 0.015 | | | | |

$V_0F_0$-No manure + no fertilizer, $V_0F_1$- No manure + RDF, $V_0F_2$: No manure + 50 % RDF, $V_1F_0$- Vermicompost (1.25 t ha$^{-1}$) + no fertilizer, $V_1F_1$- Vermicompost (1.25 t ha$^{-1}$) + RDF, $V_1F_2$- Vermicompost (1.25 t ha$^{-1}$) + 50 % RDF, $V_2F_0$- Vermicompost (2.50 t ha$^{-1}$) + no fertilizer, $V_2F_1$- Vermicompost (2.50 t ha$^{-1}$) + RDF, $V_2F_2$- Vermicompost (2.50 t ha$^{-1}$) + 50 % RDF, $V_3F_0$- Vermicompost (3.75 t ha$^{-1}$) + no fertilizer, $V_3F_1$- Vermicompost (3.75 t ha$^{-1}$) + RDF, $V_3F_2$- Vermicompost (3.75 t ha$^{-1}$) + 50 % RDF. CD (5 %) = Critical difference at 5 %, SEm(±) = Standard error of the mean.

**Table 6.** Effect of vermicompost and fertilizer on Mn mineralization

| Treatments | Total Mn (mg kg$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Stages of observation | | | | | |
| | 0 DAI | 30 DAI | 60 DAI | 90 DAI | 120 DAI | Mean |
| $V_0F_0$ | 3.08 | 3.08 | 3.08 | 3.06 | 3.06 | 3.07 |
| $V_0F_1$ | 3.10 | 3.10 | 3.10 | 3.06 | 3.06 | 3.08 |
| $V_0F_2$ | 3.08 | 3.09 | 3.08 | 3.06 | 3.06 | 3.07 |
| $V_1F_0$ | 3.12 | 3.18 | 3.26 | 3.19 | 3.16 | 3.18 |
| $V_1F_1$ | 3.18 | 3.22 | 3.27 | 3.23 | 3.22 | 3.22 |
| $V_1F_2$ | 3.16 | 3.20 | 3.27 | 3.22 | 3.20 | 3.21 |
| $V_2F_0$ | 3.17 | 3.28 | 3.34 | 3.23 | 3.21 | 3.24 |
| $V_2F_1$ | 3.20 | 3.29 | 3.34 | 3.26 | 3.24 | 3.27 |
| $V_2F_2$ | 3.18 | 3.28 | 3.34 | 3.25 | 3.22 | 3.26 |
| $V_3F_0$ | 3.32 | 3.37 | 3.43 | 3.40 | 3.36 | 3.38 |
| $V_3F_1$ | 3.34 | 3.39 | 3.45 | 3.42 | 3.38 | 3.40 |
| $V_3F_2$ | 3.33 | 3.38 | 3.44 | 3.41 | 3.38 | 3.39 |
| Mean | 3.19 | 3.24 | 3.28 | 3.23 | 3.21 | |
| | CD (5 %) | SEm(±) | | | | |
| Stages (S) | NS | 0.004 | | | | |
| Vermicompost (V) | 0.011 | 0.004 | | | | |
| S × V | NS | 0.009 | | | | |
| Fertilizers (F) | NS | 0.003 | | | | |
| S × F | NS | 0.008 | | | | |
| V × F | NS | 0.007 | | | | |
| S × V × F | NS | 0.015 | | | | |

$V_0F_0$-No manure + no fertilizer, $V_0F_1$- No manure + RDF, $V_0F_2$: No manure + 50 % RDF, $V_1F_0$- Vermicompost (1.25 t ha$^{-1}$) + no fertilizer, $V_1F_1$- Vermicompost (1.25 t ha$^{-1}$) + RDF, $V_1F_2$- Vermicompost (1.25 t ha$^{-1}$) + 50 % RDF, $V_2F_0$- Vermicompost (2.50 t ha$^{-1}$) + no fertilizer, $V_2F_1$- Vermicompost (2.50 t ha$^{-1}$) + RDF, $V_2F_2$- Vermicompost (2.50 t ha$^{-1}$) + 50 % RDF, $V_3F_0$- Vermicompost (3.75 t ha$^{-1}$) + no fertilizer, $V_3F_1$- Vermicompost (3.75 t ha$^{-1}$) + RDF, $V_3F_2$- Vermicompost (3.75 t ha$^{-1}$) + 50 % RDF. CD (5 %) = Critical difference at 5 %, SEm(±) = Standard error of the mean.

## Copper

The impact of graded doses of vermicompost, either alone or in combination with different fertiliser levels, on the status of DTPA extractable Cu (mg kg$^{-1}$) during the incubation period was in tune with the status of DTPA extractable Fe and the data have been presented in Table 4. The content of DTPA extractable Cu increased significantly with increasing levels of vermicompost irrespective of incubation stages from 0.71 to 0.79 mg kg$^{-1}$. However, the effect of varying fertilizer doses and incubation stages on DTPA-extractable Cu was found to be non -significant. Regardless of fertilizer doses, an increasing trend was observed in DTPA extractable Cu in soil up to 65 days of incubation then declined there after which is in accordance with findings of Washimkar (1997) (21). The treatment receiving highest dose of vermicompost (3.75 t ha$^{-1}$) along with RDF recorded 8.00 %, 8.30 %, 12.81 %, 11.97 % and 11.40 % increase over control at 0, 30, 65, 100 and 120 days after incubation, respectively. The interaction effects were found non-significant. Higher levels of vermicompost led to a significant increase in available Cu content throughout the incubation period.

The increase in DTPA extractable Cu might be due to release of organic acid from organic manures like vermicompost results in solubilization of metal micronutrients. These results are in agreement with findings of several researchers (15, 20).

## Zinc

The available Zn content increased up to 65 DAI and subsequently displayed a decreasing trend until 120 DAI (Table 5). The increasing levels of vermicompost resulted in significantly higher content of available Zn, ranging from 0.74 to 0.86 mg kg$^{-1}$. However, the effect of varying fertilizer doses and incubation stages on DTPA-extractable Zn was found to be non-significant. This consistent trend persisted throughout the entire incubation period (0-120 DAI). The available Zn content during starting of incubation ranged from 0.741 to 0.839 mg kg$^{-1}$, 0.745 to 0.856 mg kg$^{-1}$at 30 DAI, 0.741 to 0.859 mg kg$^{-1}$ at 65 DAI, 0.740 to 0.849 mg kg$^{-1}$at 100 DAI and 0.737 to 0.842 mg kg$^{-1}$ at 120 DAI. The treatment $V_3F_2$that received the highest dose of vermicompost (3.75 t ha$^{-1}$) along with 100 % RDF recorded 13.65 %, 15.95 %, 16.35 %, 15.00 % and 14.05 % increase over control at 0, 30, 65, 100 and 120 days after incubation, respectively. The interaction effects were found non-significant. The increase in DTPA extractable Zn might be attributed to the fact that application of vermicompost enhances the complex action of Zn by organic ligands and microbial immobilization of Zn. These results align with those of numerous other researchers (15, 19, 20).

## Manganese

A similar trend to the available Zn content was observed for DTPA extractable Mn content (Table 6), where increasing levels of vermicompost resulted in significantly higher levels of available Mn, ranging from 3.076 to 3.387 mg kg$^{-1}$. However, the effect of different fertilizer levels on DTPA extractable Mn was found to be non-significant. The available Mn content increased significantly up to 65 days after implantation (DAI) and subsequently displayed a decreasing trend until 120 DAI. The interaction effects were found non-significant. The treatment that received the highest dose of vermicompost (3.75 t ha$^{-1}$) along with 100 % RDF recorded 8.57 %, 10.06 %, 11.95 %, 11.14 % and 9.71 % increase over control at 0, 30, 65, 100 and 120 days after incubation. The increase in available Mn content during the initial 65 days of incubation can be attributed to the decomposition of organic matter present in the vermicompost, which releases organic acids that solubilize Mn in the soil. The observed increase in available Mn content with higher doses of vermicompost can be attributed to the greater release of organic acids resulting from increased vermicompost application. This finding aligns with previous studies conducted by several other researchers (15, 19, 20).

The rise in micronutrient levels could be attributed to the ability of micronutrient cations to form complexes with organic matter and become part of its structural composition. As organic matter decomposes, these cations are gradually released into the soil solution. Additionally, cationic micronutrients form organo-metallic complexes, or chelates, with organic molecules, preventing their precipitation and ensuring their availability in the soil. Some microorganisms also assimilate these cations for metabolic transformations, temporarily immobilizing them in their bodies, which are slowly released after the death of the microbes through mineralization. This can be attributed to the positive impact of vermicompost in facilitating the mineralization of both native nutrients and its own nutrient content by promoting favourable conditions for microbial and chemical activities, thereby increasing the available nutrient pool in the soil.

## Conclusion

It can be concluded that vermicomposting is one of the most promising ways to recycle and reduce the amount of organic waste, as well as produce soil fertilizers and conditioners. It allows for the diversion of organic waste from landfills by harnessing the natural processes of worms, reducing the environmental burden associated with waste disposal. The resulting vermicompost is a valuable resource that can be utilized to enhance soil fertility, promote plant growth and support sustainable agricultural practices. The nutrient content and organic matter in the household waste-based vermicompost used in this study contributed to improved micronutrient availability in the soil, which may also enhance soil health, increase water retention and reduce dependence on chemical fertilizers in the long term. This research paper investigates the effect of household waste-based vermicompost on soil micronutrient mineralization. The findings reveal that applying increasing levels of vermicompost and inorganic fertilizer, either individually or in combination, resulted in a corresponding increase in the available micronutrient content of the soil. The highest dose of vermicompost (3.75 t $ha^{-1}$) combined with the full recommended dose of fertilizer (RDF) proved to be the most effective treatment.

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## Authors' contributions

AK contributed to the conceptualization and methodology of the study, carried out the investigation and was actively involved in drafting and revising the manuscript. SJ co-developed the conceptual framework and methodology, provided resources and supervision and contributed to both drafting and reviewing the manuscript. SP supported the study by providing resources and supervision and participated in drafting and editing the manuscript. SS provided necessary resources and contributed to the supervision of the research work. ST was involved in writing the original draft and assisted in manuscript review and editing. All authors have read and approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest:** The authors do not have any conflict of interest to declare.

**Ethical issues:** None

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