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Temporal Variation in Micronutrient Content in Soil Amended with Thermochemical Organic Fertilizer Prepared from Different Reagent Combinations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A laboratory incubation study was carried out in the Department of Soil Science and Agricultural Chemistry, for 90 days to assess the dynamics of micronutrient release from Thermochemical Organic Fertilizer (TOF) prepared using different reagent combinations. Two kg air dried 2 mm

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sieved soil was taken in 3 kg container pots. The study was laid in Completely Randomized Design with 6 treatments and 3 replications. Treatments were, T_1: FYM @20 t ha^{-1}; T_2:TOF prepared from 5% acetic acid and 10 % Calcium hydroxide [TA_5CH_{10}]; T3: TOF prepared from 5% acetic acid and 15 % Calcium hydroxide [TA_5CH_{15}]; T_4: TOF prepared from 10% acetic acid and 10 % Calcium hydroxide [$TA_{10}CH_{10}$]; T_5:Patented TOF and T_6: Control (Soil alone). Fe, Mn Zn and B exhibited a gradual and progressive release pattern throughout the incubation period. Whereas Copper (Cu) availability showed a decreasing trend from the 30th day onwards. Hence it can concluded that TOF significantly improved the micronutrient availability in soil compared to the FYM based and control treatment.

Keywords: Thermochemical organic fertilizer (TOF); nutrient releasing pattern; micronutrients; organic fertilizers.

1. INTRODUCTION

Micronutrients, though required by plants in trace amounts (typically less than 100 mg kg^{-1} dry weight), are essential for numerous physiological, biochemical, and metabolic functions. Elements such as boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) play critical roles in processes like gene expression, hormone perception, chlorophyll synthesis, signal transduction energy metabolism, and reproductive development. While these nutrients are generally present in soils, their bioavailability is often limited, making deficiencies increasingly common—especially under intensive cultivation, soil degradation, and with modern high-yielding crop varieties (Tripathi *et al*., 2015).

Organic fertilizers, irrespective of their source, have been reported to supply essential micronutrients to the soil (Richards *et al*., 2011; Dey *et al*., 2019; Dhaliwal *et al*., 2020). The mineralization of nutrients from applied manure is influenced by various factors such as soil type, soil moisture and temperature conditions, the properties of the manure, and the activity of soil microorganisms, among others (Moorhead *et al*. 1996). Because the influence of these factors cannot be precisely measured, nutrient mineralization from organic amendments can only be estimated. To optimize the use of macro- and micronutrients from organic fertilizers, it is essential to evaluate the mineralization potential and pattern of each amendment and take it into account when determining application rates (Eghball *et al*. 2002) and time of application.

Incubation studies offer a controlled method for assessing the temporal dynamics of nutrient release from organic fertilisers. Such studies can help improve nutrient management strategies, by tracking the concentration of available micronutrients over time. Therefore, this study aims to investigate the release patterns of selected micronutrients from different organic fertilizers during an incubation period, with the objective of understanding their potential contribution to plant-available micronutrient pools in soil.

2. MATERIALS AND METHODS

A 90-days soil incubation study was conducted under controlled laboratory conditions at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, to evaluate the effect of different organic fertilizers on nutrient availability and nutrient releasing patterns. The experimental layout followed Completely Randomized Design (CRD) with 10 treatments and 3 replications. Two kg air dried 2 mm sieved soil was taken in 3 kg container pots. Treatments were applied on surface and thoroughly mixed. This was maintained at field capacity. Thermochemical Organic Fertilizer (TOF) was produced as per patented KAU rapid thermochemical processing technology developed by Sudharmaidevi *et al*. (2017). The chemical reagents were substituted with user friendly reagents such as acetic acid and calcium hydroxide. Treatments were, T1: FYM; T2:TOF prepared from 5% acetic acid and 10 % Calcium hydroxide [TA_5CH_{10}]; T3: TOF prepared from 5% acetic acid and 15 % Calcium hydroxide [TA_5CH_{15}]; T4: TOF prepared from 10% acetic acid and 10 % Calcium hydroxide [$TA_{10}CH_{10}$]; T5: Patented TOF and T6: Control (Soil alone). FYM was applied as per KAU Package of Practice (POP) recommendation for cowpea (KAU, 2016) and TOF was applied in terms of nitrogen equivalence of FYM as per POP. Soil samples were drawn at 0, 15, 30, 60, and 90th day of incubation analysed for available Fe, Mn, Zn and Cu, by 0.1 *N* HCl extraction and atomic absorption spectrophotometry (Sims *et al*., 1991) and B by hot water extraction and Azomethine – H method (Gupta, 1967).

3. RESULTS AND DISCUSSION

3.1 Micronutrient Dynamics in the Soil

The variation in available Fe in each sampling interval during the incubation study can be noted from the Table 1. All the treatments except control exhibited increase in the available Fe during the sampling period from zero days to 30 days, followed by a decline up to 60 days and further increase up to 90 days. Treatment T5 exhibited highest available Fe throughout incubation period which was statistically on par with T4 whereas lowest available Fe content was recorded by control. Continued application of organic fertilizer along with inorganic fertilizers has resulted in microbial breakdown of organic matter releasing both micronutrients and complexing compounds—such as organic acids and humic substances—which aided in the transfer of these micronutrients from the solid phase into the soil solution (Zhang *et al*., 2015).The solubility of micronutrients, including iron, typically increases as soil pH decreases, since pH strongly influences the ratio between the more soluble ferrous form and the less soluble ferric form of iron (Prasad & Sinha 1982).A decrease in pH was observed when amended with organic fertilizers because of the release of organic acids (Arulkumar *et al*., 2022; El-Ngar *et al*., 2022; Guo *et al*.,2022).

Available Mn content showed significant variation among treatments from 15th day onwards (Table 2). For all the treatments, the available Mn increased throughout the incubation period. The highest values of available Mn were recorded by T5 which was statistically on par with T4 while the lowest values of the same were showed by control throughout the incubation study. Similar results were also obtained by Tsering *et al.,* 2024. The increase in available manganese (Mn) content may be attributed to the decomposition of the added organic matter, which likely released protons into the soil solution and reduced both the soil's redox potential (Eh) and pH. These changes would have facilitated the dissolution and reduction of Mn, thereby enhancing its availability (Zhang *et al*., 2015).

The treatments caused considerable variations in the available Zn in soil at different intervals (Table 3). All the treatments except absolute control showed increase in the available Zn from zero days to 60 days followed by a decrease. However, considerable fluctuations in the available Zn can be observed for the control throughout the incubation study. The highest values of available Zn were exhibited by T4 which was statistically on par with T5 while lowest values of the same were displayed by control during the entire incubation period. Soil pH is one of several key factors affecting the availability of zinc (Zn) to plants (Anderson & Christensen, 1988), with Zn availability generally increasing as soil pH decreases (Alloway, 2008). Additionally, the organic matter content of soil can influence Zn availability through multiple mechanisms (Moody *et al*., 1997). Specifically, higher levels of organic matter can lead to an increase in the exchangeable and organically bound forms of Zn, while reducing the proportion bound to oxides, largely due to changes in redox conditions (Zhang *et al*., 2015).

Table 1. Effect of treatments on soil available Iron content at different periods of incubation, mg kg^{-1}

Treatment	Period				
	0 D	**15 D**	**30 D**	**60 D**	**90 D**
T_1- Soil+ FYM	7.52 ± 0.53^{cd}	9.59 ± 0.95^{b}	11.36 ± 0.76^{c}	9.46 ± 0.60^{d}	11.39 ± 0.73^{c}
T_2- soil+100 % TA_5CH_{10}	9.06 ± 0.16^{ab}	9.57 ± 1.00^{b}	12.50 ± 0.25^{bc}	11.53 ± 0.79^{c}	13.12 ± 0.79^{b}
T_3 –soil+100 % TA_5CH_{15}	8.37 ± 0.61^{bc}	10.33 ± 0.97^{b}	12.41 ± 0.98^{c}	10.12 ± 0.55^{d}	12.25 ± 0.61^{bc}
T_4 – soil+100 % $TA_{10}CH_{10}$	9.31 ± 0.91^{ab}	10.56 ± 0.64^{ab}	13.73 ± 0.79^{ab}	12.62 ± 0.23^{b}	13.57 ± 0.85^{ab}
T_5 – soil+100 % TOF(P)	9.86 ± 0.93^{a}	11.88 ± 0.09^{a}	13.85 ± 0.74^{a}	13.88 ± 0.79^{a}	14.82 ± 0.75^{a}
T_6 – Soil alone	7.06 ± 0.58^{d}	6.74 ± 0.48^{c}	7.40 ± 0.49^{d}	5.79 ± 0.48^{e}	6.71 ± 0.73^{d}
SE(m)±	0.39	0.44	0.41	0.35	0.43
CD (0.05)	1.19	1.35	1.26	1.08	1.33

Table 2. Effect of treatments on soil available manganese content at different periods of incubation, mg kg^{-1}

Treatments	Period				
	0 D	15 D	30 D	60 D	90 D
T_1- Soil+ FYM	2.00 ± 0.05	3.60 ± 0.01^{a}	4.25 ± 0.05^{cd}	6.58 ± 0.03^{b}	6.81 ± 0.51^{c}
T_2- soil+100 % TA_5CH_{10}	2.54 ± 0.08	3.48 ± 0.03^{b}	4.35 ± 0.12^{c}	6.20 ± 0.04^{d}	7.09 ± 0.04^{bc}
T_3 –soil+100 % TA_5CH_{15}	2.46 ± 0.06	3.19 ± 0.07^{c}	4.13 ± 0.09^{d}	6.00 ± 0.12^{e}	7.00 ± 0.07^{bc}
T_4 – soil+100 % $TA_{10}CH_{10}$	2.60 ± 0.09	3.55 ± 0.04^{ab}	4.50 ± 0.06^{b}	6.45 ± 0.06^{c}	7.34 ± 0.08^{ab}
T_5 – soil+100 % TOF(P)	2.68 ± 0.65	3.61 ± 0.02^{a}	4.95 ± 0.01^{a}	6.80 ± 0.04^{a}	7.55 ± 0.08^{a}
T_6 – Soil alone	2.35 ± 0.06	2.09 ± 0.04^{d}	2.49 ± 0.05^{e}	4.51 ± 0.03^{f}	6.08 ± 0.13^{d}
SE(m)±	0.16	0.02	0.04	0.04	0.13
CD (0.05)	-	0.07	0.13	0.11	0.39

Table 3. Effect of treatments on soil available zinc content at different periods of incubation, mg kg^{-1}

Treatments	Period				
	0 D	15 D	30 D	60 D	90 D
T_1- Soil+ FYM	1.14 ± 0.15^{a}	1.26 ± 0.15^{abc}	1.38 ± 0.12^{c}	1.65 ± 0.27^{c}	1.25 ± 0.14^{c}
T_2- soil+100 % TA_5CH_{10}	1.16 ± 0.06^{a}	1.22 ± 0.10^{bc}	1.52 ± 0.07^{bc}	1.97 ± 0.06^{b}	1.60 ± 0.13^{ab}
T_3 –soil+100 % TA_5CH_{15}	1.12 ± 0.06^{a}	1.16 ± 0.12^{c}	1.48 ± 0.09^{c}	1.95 ± 0.07^{b}	1.54 ± 0.09^{b}
T_4 – soil+100 % $TA_{10}CH_{10}$	1.19 ± 0.05^{a}	1.39 ± 0.08^{ab}	1.70 ± 0.07^{a}	2.23 ± 0.10^{a}	1.79 ± 0.13^{a}
T_5 – soil+100 % TOF(P)	1.24 ± 0.11^{a}	1.44 ± 0.11^{a}	1.67 ± 0.12^{ab}	2.18 ± 0.11^{ab}	1.74 ± 0.12^{ab}
T_6 – Soil alone	0.91 ± 0.06^{b}	0.85 ± 0.08^{d}	0.93 ± 0.08^{d}	0.96 ± 0.12^{d}	0.90 ± 0.13^{d}
SE(m)±	0.05	0.06	0.05	0.08	0.07
CD (0.05)	0.16	0.19	0.17	0.25	0.22

Significant variations in available Cu content among treatments can be observed throughout the incubation period (Table 4). All the treatments except T6 exhibited increase in the available Cu in the initial 30 days and declined thereafter up to 90 days during the incubation study. Control has shown fluctuating trend with occasional increase and decrease in the available Cu content during the entire incubation period. The highest value of available Cu was recorded by T4 which was statistically on par with T5 and T2 whereas lowest values of the same were exhibited by control throughout the incubation study. The rise in soil copper (Cu) content after the application of organic matter (OM) can be explained by the adsorption of Cu^{2+} ions onto the OM. Similar results with thermochemical organic fertilizer have also been reported by Leno and Sudharmaidevi, 2018. Sorption and complexation reactions with OM play a key role in determining Cu availability, as copper readily forms strong inner-sphere complexes with soil organic matter (SOM) (Boudesocque *et al*., 2007). Moreover, the use of organic manures increases the organically bound fraction of Cu while reducing its soluble and extractable forms (Bolan *et al*., 2003), which can ultimately lower its availability for plant uptake.

The variation of available B between treatments during each sampling period can be noted from the Table 5. The values of available B increased for all the treatments except for Control. The highest values of available B were recorded by T5 which was statistically on par with T4 while lowest values of the same were showed by control during the entire incubation period. Soil B availability was primarily governed by the transformation and distribution of its various fractions. The application of organic amendments

Table 4. Effect of treatments on soil available copper content at different periods of incubation, mg kg^{-1}

Treatments	Period				
	0 D	**15 D**	**30 D**	**60 D**	**90 D**
T_1- Soil+ FYM	1.31 ± 0.02	1.32 ± 0.03^c	1.51 ± 0.05^b	1.38 ± 0.02^d	1.23 ± 0.02^d
T_2- soil+100 % TA_5CH_{10}	1.35 ± 0.03	1.51 ± 0.04^b	1.75 ± 0.05^a	1.54 ± 0.03^{bc}	1.38 ± 0.03^{bc}
T_3 – soil+100 % TA_5CH_{15}	1.31 ± 0.04	1.49 ± 0.02^b	1.72 ± 0.04^a	1.52 ± 0.04^c	1.36 ± 0.04^c
T_4 – soil+100 % $TA_{10}CH_{10}$	1.36 ± 0.03	1.58 ± 0.05^a	1.80 ± 0.05^a	1.61 ± 0.03^a	1.44 ± 0.04^{ab}
T_5 – soil+100 % TOF(P)	1.36 ± 0.04	1.54 ± 0.04^{ab}	1.77 ± 0.05^a	1.58 ± 0.02^{ab}	1.45 ± 0.06^a
T_6 – Soil alone	1.30 ± 0.04	1.28 ± 0.04^c	1.31 ± 0.03^c	1.26 ± 0.04^e	1.14 ± 0.02^e
SE(m)±	0.02	0.02	0.03	0.02	0.02
CD (0.05)	-	0.06	0.08	0.05	0.06

Table 5. Effect of treatments on hot water soluble boron content at different periods of incubation, mg kg^{-1}

Treatments	Period				
	0 D	**15 D**	**30 D**	**60 D**	**90 D**
T_1- Soil+ FYM	0.43 ± 0.03^d	0.54 ± 0.03^c	0.65 ± 0.03^b	0.68 ± 0.04^c	0.75 ± 0.04^d
T_2- soil+100 per cent TA_5CH_{10}	0.50 ± 0.02^c	0.58 ± 0.01^c	0.63 ± 0.02^b	0.73 ± 0.02^{bc}	0.77 ± 0.03^{cd}
T_3 –soil+100 per cent TA_5CH_{15}	0.53 ± 0.02^{bc}	0.61 ± 0.01^b	0.65 ± 0.04^b	0.75 ± 0.03^b	0.81 ± 0.02^{bc}
T_4 – soil+100 per cent $TA_{10}CH_{10}$	0.56 ± 0.01^{ab}	0.64 ± 0.02^{ab}	0.67 ± 0.02^{ab}	0.78 ± 0.04^{ab}	0.83 ± 0.03^{ab}
T_5 – soil+100 per cent TOF(P)	0.58 ± 0.01^a	0.65 ± 0.01^a	0.72 ± 0.03^a	0.81 ± 0.03^a	0.87 ± 0.03^a
T_6 – Soil alone	0.34 ± 0.05^e	0.36 ± 0.03^d	0.42 ± 0.03^c	0.37 ± 0.03^d	0.45 ± 0.03^e
SE(m)±	0.01	0.01	0.02	0.02	0.02
CD (0.05)	0.05	0.03	0.05	0.05	0.05

increased the readily available and specifically adsorbed forms of B, thereby improving its availability in the soil and fortified TOF have been reported to have higher B content when compared to other organic fertilizers (Ajayan & Thampatti, 2021).

4. CONCLUSION

The study can be concluded with the fact that TOF prepared using alternate reagent combinations significantly improved the micronutrient dynamics in soil. Fe, Mn, Zn and B exhibited a gradual and progressive release pattern throughout the incubation period. Whereas Cu availability exhibited a decreasing pattern from 30th day of incubation. T5 (patented TOF) and T4 (TOF prepared using 10% acetic acid and 10% $Ca(OH)_2$) were significantly more effective in enhancing soil micronutrient availability compared to other reagent combinations, FYM and control.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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