

Spatiotemporal Speciation of Micronutrients in Organic Compost and Their Efficacy in Enhancing *Triticum aestivum* L. Yield

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ARTICLE INFO

Vol. 3, Issue 2, 2024

Pages: 327-338

Received:

2024-11-23

Revised:

2024-12-12

Accepted:

2024-12-31

Keywords:

Composite Formation,
Micro-nutrients, Wheat
Cultivation, Speciation
and Bioavailability,
Micronutrient
Proportions.

ABSTRACT

This study explored the impact of organic compost sourced from a three-month aerobic decomposition of poultry manure, farmyard manure, and green manure on soil health and wheat (*Triticum aestivum* L.) productivity. Organic additives, featuring an EC of 2.2 dSm⁻¹ and a pH of 7.5, were applied to the soil with a benchmark pH of 8.06 and EC of 0.58 dSm⁻¹ to examine their potential to enrich micronutrient retention and soil structure. By using the A-B DTPA methodology, soil extraction and wet digestion for plant tissue analysis, the experiment emphasized the speciation and bioavailability of micronutrients. The findings imply that the application of 15 tha⁻¹ (T4) yielded the most notable improvements, followed in order by the 10t ha⁻¹ (T3) dosage; specifically, post-harvest(production) soil analysis in T4 revealed micronutrient proportions of 2.7, 0.55, and 2.81 mg kg⁻¹ for Cu, Zn, and Fe, respectively. This nutrient supplementation resulted in appreciable enhanced agronomic productivity, including a 40% increase in total wheat output, an 18% increase in spike size, and a 14.2% rise in fresh biomass yield. Furthermore, plant tissue analytical assessment confirmed the improved uptake in T4, with Cu, Zn, and Fe concentration level reached up to 18.6, 79.3, and 33.3 mg kg⁻¹, respectively.



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Introduction

Over the multiple decades, agricultural practices have gone through significant progress in order to satisfy the demands of an expanding population. Food security has been achieved by the industrialization of agricultural sectors such as dairy farming, crop production, protein farming, and large-scale food processing, but it also produces a lot of waste in the form of animal dung, crop residues, and leftovers from the food industry. If ignored, these wastes might seriously harm the ecology and the condition of the soil. These waste products are transformed into useful ones using a variety of techniques. Among these methods, composting waste materials to produce valuable organic fertilizer is thought to be a practical and economical strategy (Hanajima et al., 2006).

Applying compost is essential for increasing agricultural output and fostering sustainability. Additionally, it provides a workable answer to the problems that farmers encounter as a result of decreasing soil fertility. Because weaker plants are less able to withstand such pressures, reduced soil fertility frequently leads to poorer agricultural yields and increased crop susceptibility to pests and diseases (Madeleine et al., 2005). The conventional method of using organic (animal) manure as a plant nutrient source through bio-degradation is composting (Uriah and Shehu, 2014).

It is a useful supply in developed nations and raises the amount of organic matter in the soil. Composting is a great alternative source in Pakistan, but it isn't used as much because of ignorance and a lack of knowledge. Many plant stalks, leaves, branches, grass clippings, and weeds are burned every day. Composting these items can greatly improve soil fertility and crop output (Sarwar, 2005).

Pathogens should not be present when aerobically degraded biologically organic wastes are composted into humus-like material, and viable seedlings utilized as a soil amendment should be stable and appropriate. Inadequate aeration and drums or pits that are too big to reach the thermophilic stage of the process might cause the composting process to stall. Long-term maturation and stability in windrows are required for the immature material that emerges from the drums or pits (Partanen et al., 2010).

Compost stability and maturity are important bioprocess parameters since the most important factors influencing the composting process are C/N ratio, temperature, moisture content, pH level, air-filled porosity, and physical structure of waste material. Numerous researchers came to the conclusion that a maturity measure that combines multiple characteristics is more adequate than one. readiness and quality of compost that could be observed via biological, physical and chemical factors, such as the C/N ratio, CO₂ assessment, pH, electrical conductivity (EC), oxygen uptake, cation exchange capacity, and humic substance formation in final products, to ascertain the phytotoxicity as a trustworthy measure of compost maturity. Compost can be used as an organic fertilizer and soil amendment on agricultural land since it is stable and rich in nutrients (Bernal et al., 2009).

The fundamental requirements for plant growth, such as support, moisture, and nutrients, are supplied by soil. Based on the concentration that the plants need, the 19 key elements that crops need are referred to as macro and micronutrients. Macronutrients are higher concentrations of nutrients that plants need. Cu, Zn, Fe, Mn, Mo, and B are regarded as micronutrients among these 19 important elements (Nazif et al., 2006). Low concentrations of micronutrients are necessary for several physiological processes, such as the respiration process, photosynthesis, and production failure or yield loss if a nutrient is lacking in the soil (Mengel et al., 2001; Nazakat et al., 2012). For instance, Zn shortage is a major yield-limiting factor in Asian countries for rice (*Oryza sativa*

L.) (Rehman et al., 2012). Micronutrients can participate in a number of significant events, including redox reactions, and function as cofactors in enzyme systems (Memon et al., 2012).

Jordao et al. (2006) conducted research on the use of compost made from urban solid waste to assess the soil's accessibility to heavy metals. The metal extraction from soil and compost was assessed using the DTPA method. The pH of the soil rises with the amount of compost added. The soil pH and accessible levels of Cu, Pb, Ni, and Zn were much higher in the higher city compost than in the smaller city compost, which came from the two distinct cities. As time goes on, adding compost to the soil increases the amount of Cu, Zn, Pb, and manganese that can be found in mixed samples.

The smaller city metal concentration in the substrate was Zn > Pb > Cu > Ni > Mn. The inclusion of compost from the big city yielded in metal concentration in order Zn > Pb > Ni > Cu > Mn. Loading the soil to maximize the quantity of micronutrients in crops is the prime study objective. Uneconomical and low agricultural production in the country may be one of the drawback things is micronutrient. Fact-based policies, latest technologies are required to be developed utilizing various management techniques to boost agricultural output. Since iron is the most important component of many enzymes, it is necessary for both plant development and chlorophyll. Iron plays a crucial role in DNA metabolism and transforms nitrate into ammonium by releasing energy from starch and sugar during the oxidation process in plants. Iron levels in plant tissues are typically between 50 and 250 ppm, but levels in dry matter of 50 ppm or less are insufficient (Nisar et al., 1996). Shaheen (2016) conducted an additional investigation to evaluate the micronutrients in soil series (Table 1).

Table 1: *Micronutrients in soil*

Parameter	Depth	Highest level (mg kg ⁻¹) & Coordinates	Lowest Level (mg kg ⁻¹) & Coordinates	Sufficiency Status
Zn	Surface	4.21 Satwal	0.22 Rajar	Satwal's 100% surface samples are generally sufficient. 97% of the surface soil is lacking
	Sub-Soil	0.30 Satwal	0.13 Rajar	100% inadequate subsurface samples
Cu	Surface	4.31 Satwal	1.28 Balkassar	No inadequacy Average 92% sufficient and 8% minimal
	Sub-Soil	2.40 Satwal	0.35 Balkassar	-
Fe	Surface	4.87 Guliana	2.36 Balkassar	Fe is inadequate in 20%, minimal in 53%, & sufficient in 27% surface soils 100% Balkassar deficient in Fe
	Sub-Soil	2.83 Guliana	1.45 Balkassar	-

Materials and Methods

Soil Micronutrient Analysis

The bioavailable fractions of Cu, Zn, and Fe were determined using the Ammonium Bicarbonate-DTPA extraction procedure (Schwab & Soltanpour, 1977). The extraction solution was synthesized by integrating 1.97 g of diethylenetriamine pentaacetic acid (DTPA) within 800 mL of distilled water, supplemented with 2 mL of 1:1 ammonium hydroxide to streamline release into the solution and manage bicarbonate effervescence (gas evolution). Following the 0.005 M DTPA was fully merged, 79.06 g of ammonium bicarbonate (NH_4HCO_3) was added under gentle shaking. The solution's pH was standardized at 7.6 using NH_4OH (ammonium hydroxide) before following dilution to a final volume of 1 L with distilled water. For the extraction & isolation, 10 g of air-dried (naturally) soil (sieved to 2 mm) was merged with 20 mL of the prepared reagent in a 125 mL conical flask and shaken on a reciprocal shaker at 180 rpm for 15 minutes. The produced suspensions were made clear via Whatman No. 42 filter paper. Micronutrient accounting & quantification were executed using an Atomic Absorption Spectrophotometer (AAS), where the proportion of nutrients was derived from emission measurements at element-specific wavelengths relative to a multi-concentration standard calibration curve.

Micronutrient cation (ppm) = ppm MC (from calibrated curve) \times Dilution factor

Analysis of Chemicals in Plants

One gram of dried and ground plant material needs to be quantitatively transferred to a 100 mL Borosilicate glass (Pyrex) digestion tube. After adding 10 milliliters (2:1) of the nitric acid perchloric acid mixture, left to stand overnight or until the intensive response phase is finished. Use tiny stemmed funnels to acid backflow into the tubes. After early-stage digestion, raise the temperature of the block digester to 150 °C and put the tubes in it for an hour. Raise the temperature gradually to 235°C until all traces of HNO_3 are eliminated. Continue the digestion process for an additional half hour once the tubes are filled with thick white HClO_4 fumes. After removing the tubes from the block-digester and letting them cool for a short while, carefully pour a relatively few drops of distilled water down the funnel. Add little amounts of distilled water to the condensing vapors to clean the walls of tubes and funnels. Bring to a boil, combine the solutions in each tube, and let aside for a few hours. There must be at least one blank reagent (no plant material) in every batch of digestion samples.

As directed by the equipment, operate the Flame Photometer or Atomic Absorption Spectrophotometer. Create a standard curve by running several suitable norms. After removing the clear liquid layer and analyzing Cu, Zn, and Fe in aliquots using an atomic absorption spectrophotometer, determine the concentrations of the clear liquid layer using the calibration curve (Rashid, 1986).

Statistical study

Using the appropriate statistical tool, all collected data were statistically evaluated. RCBD was used to generate an ANOVA, and the least (minimal) significant difference test was designed to analyze means at a 95% confidence level.

Results

Basic Soil Properties

Table 2 displays the basic characteristics of the soil that was established prior to the treatment. Prior to being applied to the field, compost characteristics were observed. Table 3 shows that the pH was 7.5 and the compost EC was 2.2 dSm⁻¹. Following oven drying, the compost's moisture content was found to be 29.8%. Cu, Zn, and Fe micronutrients in compost were determined using the wet digestion method. As summarized in the table, the concentrations (fraction) of Cu were 70–80 (mg kg⁻¹), Zn were 160–170 (mg kg⁻¹), and Fe were 212–225 (mg kg⁻¹). As summarized in Table 3, also illustrates the temperature of the composting at various depths and stages. 26 to 35 degrees' Celsius temperature ranged at start of the process. The initial temperature within 30 days of the composting process in pits increased to 35–40 degrees Celsius.

Table 2: *General Characteristics of Soil Prior to Field Use*

Parameters	Soil	Units
EC	0.87±0.22	dSm ⁻¹
pH	8.16±0.2	–
Copper	2.29±0.04	mg kg ⁻¹
Zinc	0.42±0.04	-
Iron	2.74±0.25	-

Table 3: *General Characteristics of Compost Before the Field Use*

Parameters	Compost	Units
EC	2.2±0.05	dSm ⁻¹
pH	7.5±0.04	-
Copper	75±0.08	mg kg ⁻¹
Zinc	162±0.12	-
Iron	216±0.03	-
Moisture Contents	29.6±0.75	%
	Low-High	
Temperature	25-35, 52-60	°C

Analysis of Soil Micronutrient Concentrations (Cu, Zn, and Fe)

As illustrated in Table 4, the analytical results of soil-derived micronutrient concentration reflect that the practice of organic additives significantly regulated the range of Cu, Zn, and Fe measured against the control group (T1). Particularly, the highest enrichment of Cu was noted in treatment T4 (15 t ha⁻¹ compost), achieving a peak level of 2.7 mg kg⁻¹, which shows an appreciable increase over the unamended control. In sequence with T3 (10 t ha⁻¹ compost) with a concentration of 2.5 mg kg⁻¹. An important observation is that, while the high-dosage treatments showed clear output, the Cu quantity levels in T2 (5 t ha⁻¹ compost) and T5 (standard NPK application) did not differ significantly relative to each other, suggesting that lower organic inputs or purely mineral fertilization have a limited impact on copper solubility. Overall, the findings emphasize that the

T4 treatment (15 t ha⁻¹ compost) is the most impactful approach for augmenting trace element (micronutrients) availability in the soil medium.

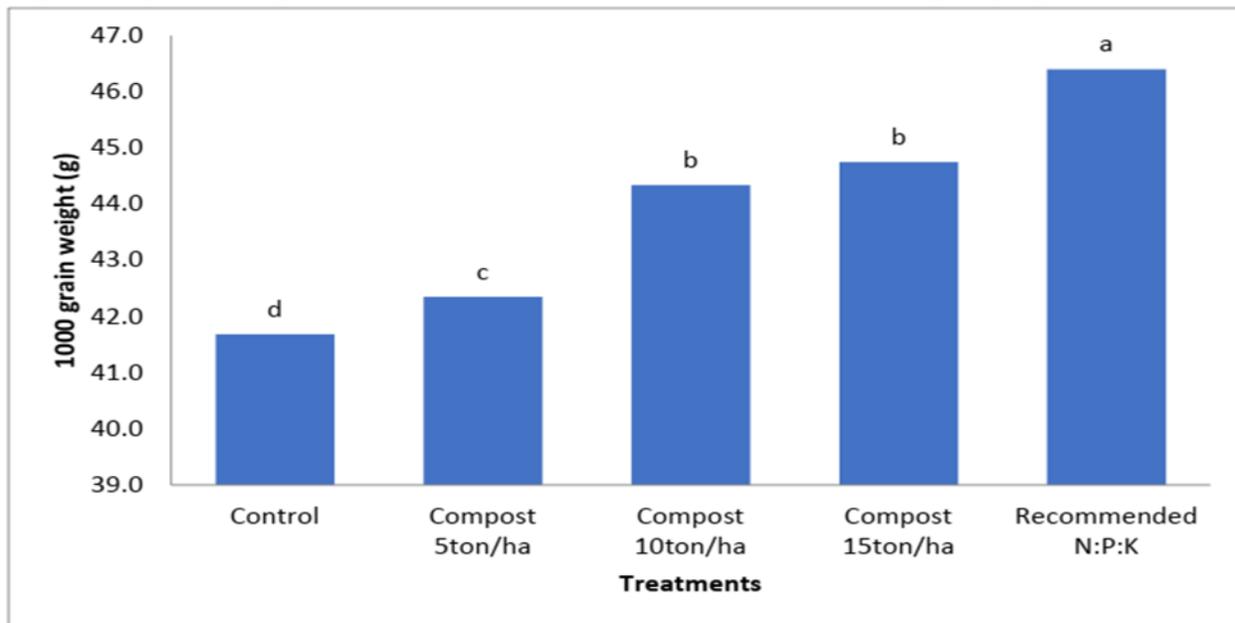
Table 4: *Quantity of Cu, Zn, and Fe Following Compost Treatment in Soil*

Application	Copper (mg kg ⁻¹)	Zinc (mg kg ⁻¹)	Iron (mg kg ⁻¹)
Control (Baseline)	2.3±0.19	0.43±0.02	2.71±0.09
Compost 5-t ha ⁻¹	2.4±0.09	0.44±0.01	2.74±0.03
Compost 10-t ha ⁻¹	2.5±0.20	0.47±0.02	2.78±0.02
Compost 15-t ha ⁻¹	2.7±0.20	0.55±0.04	2.81±0.01
Proposed N:P:K	2.4±0.11	0.46±0.02	2.77±0.02

Estimation of One Thousand Grain Yield

The outcomes of experiments, illustrated in Figure 1, reveal that the mixed compost (MC) application and inorganic fertilizers favorably influenced the 1000-grain weight of (*Triticum aestivum* L.) wheat. The highest grain weight was reported in the recommended NPK group (T5), which measured at 46.4g—a remarkable 10% increase relative to the control (T1), which consequently produced the maximum weight of 41.7g. Among the organic treatments & application, T4 (15 t ha⁻¹ compost) reveals the most considerable impact with a weight of 44.8g (a 6.9 percent increase), followed closely by T3 (10 t ha⁻¹ compost), which reached 44.3g. These findings correlate with the findings of Antil et al. (2013), who found that incorporated nutrient management by means of mixed compost (MC) significantly maximizes grain maturation and overall productivity. The data derived confirms a clear-cut dose-response correlation, where increasing the compost quantity rate leads to a quantifiable enhancement in grain density and weight in comparison with unamended soil.

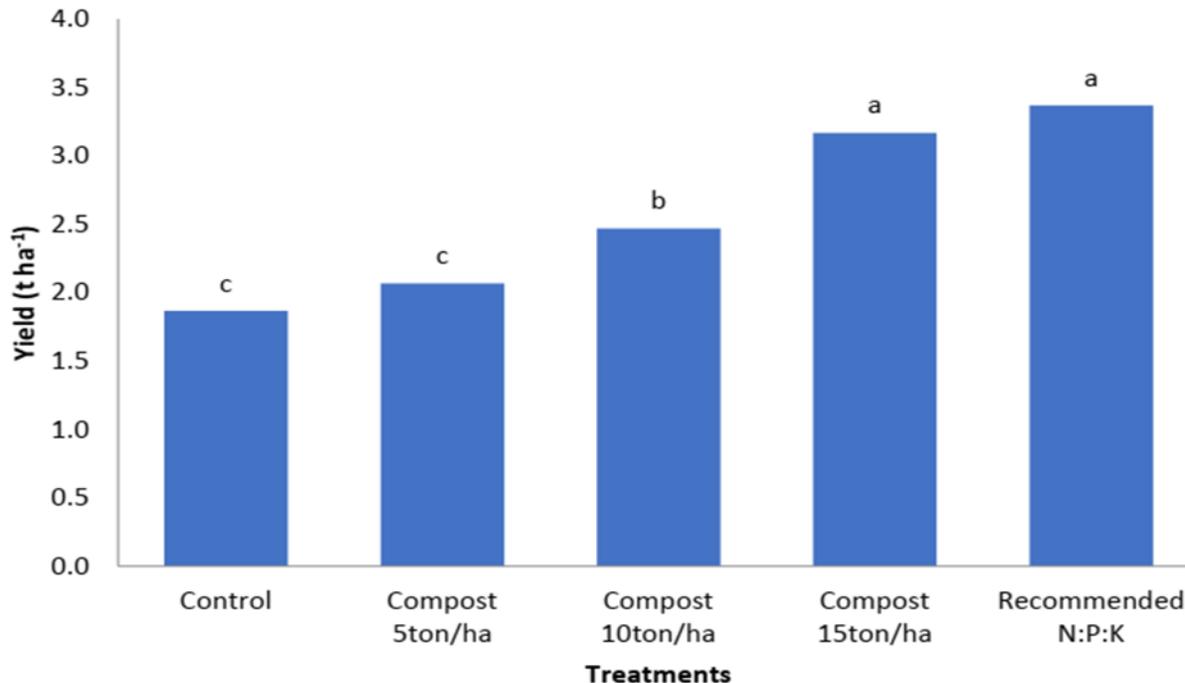
Fig 01: *Organic Compost and Mineral Fertilization on 1,000-Grain Weight (g) of Wheat.*



Findings of Wheat Crop Yield (tha-1)

As comparison to the control treatment (T1), the application of mixed compost (MC) enhanced weight yield (tha-1). Figure 2. shown the findings of the recommended NPK application, T5, considerably enhanced 3.4 tha⁻¹, after which T4 (compost at 15 t ha⁻¹) 3.2 tha-1 as compared to the T1 control 1.9 tha-1, respectively.

Fig 02: Comparative Effects of Organic Compost and Recommended N-P-K



Analysis (Cu, Zn & Fe) accumulation on Wheat

The different concentrations of Cu, Zn, and Fe are shown in Table 5. According to them, the results revealed that treatment T4 (compost @ 15 t ha⁻¹) had the maximized concentration of Cu (18.6 mg ka-1), followed by treatment T3 (compost @ 10 t ha-1) (15.6 mg kg-1).

Similar trends were observed in the accumulation of Zinc and Iron within the plant tissues, with the highest concentrations consistently associated with the 15 t ha⁻¹ compost application (T4). For Zinc, T4 achieved a peak concentration of 79.3 mg kg⁻¹, followed by T3 (10 t ha⁻¹) at 76.1 mg kg⁻¹, both representing a significant improvement over the baseline of 73.7 mg kg⁻¹ observed in the control group (T1). It is noteworthy that no statistically marked variation was identified between the Zn levels of T2 and T5, indicating for this specific element an equivalent influence among low-rate organic additives and mineral fertilization. Pertaining to iron (Fe) content, T4 again confirmed the most remarkable uptake at 33.3 mg kg⁻¹, subsequently followed by T3 at 31.3 mg kg⁻¹. Statistical evaluation confirmed that T3 also offered a significant boost in Iron (Fe) quantity levels assessed against T2 (28.3 mg kg⁻¹) and the unamended (application) control. In line with the Zinc findings, the iron (Fe) concentrations for treatments T2 and T5 showed no statistically significant change, being different from one another. Collectively, the data support the conclusion that higher application (dosage) rates of compost are requisite for significantly boosting the micronutrient profile of the crop, apart from the range delivered by standard NPK or low-volume organic inputs.

Table 5: Fraction of Cu, Zn, and Fe in Wheat Following Compost Treatment

Application	Copper (mg kg ⁻¹)	Zinc (mg kg ⁻¹)	Iron (mg kg ⁻¹)
Control (Baseline)	9.96 d	73.7 c	24.0 d
Compost 5 t ha ⁻¹	12.2 c	74.8 c	28.3 c
Compost 10 t ha ⁻¹	15.5 b	76.1 b	31.4 b
Compost 15 t ha ⁻¹	18.6 a	79.3 a	33.3 a
Proposed N:P:K	12.3 c	74.4 c	28.6 c

Discussion

The starting temperature of composting, according to Goyal et al. (2005), was between 28 and 35 degrees Celsius. In addition to serving as a key factor for reducing various pathogens and other efficient biological processes, the temperature rise. The greatest temperature quantified in the period of the thermophilic stage was between 47 and 55 degrees Celsius (Table 2). After fifty (50) to sixty (60) days of organic waste recycling (composting), the temperature peaks in the range of 53 to 60 degrees Celsius. Similar outcomes confirmed that the composting conjunction achieved a high temperature phase (thermophilic) higher than 45°C and reached a maximum at 60°C.

The organic waste recycling (composting) phase was featured by a discrete thermophilic upswing, where the internal temperature rose considerably due to the exothermic features of microbial organic matter degradation. Following this, a maximum progressive cooling phase was noticed as the material reached a degree of maturity after several months. In later stages of field trials, the incorporation of varying compost dosages covering a range from low to high application rates illustrated a clear dose-responsive improvement in soil and plant attributes. The highest dosage (T4) at the time of harvest, in a consistent manner, outperformed the moderate (T3) and low-rate treatments, particularly in relation to the storage of essential micronutrients such as Copper, Zinc, and Iron. These results correspond with the key findings of Amlinger et al. (2007), who noted that enriched organic amendments refine trace element availability relative to unamended controls.

Additionally, the merging of compost constructively transformed the overall soil chemistry, contributing to an evident increase in accessible macronutrients (NPK) and secondary nutrients. This physiological response of the wheat crop is due to the enrichment of the soil matrix. The highest grain mass (weight) and overall yield (outcomes) metrics were observed in the treatments gaining the maximum compost application, reinforcing the outcomes of Ahmad et al. (2008) and Bajpai et al. (2002). These studies collectively suggest that enhanced nutrient absorption, facilitated by the organic matter in compost, is the primary driver behind the significant improvements in crop growth and final grain weight.

Bedada et al. (2014) reported similar results: maximum wheat production increased in the sequence of fertilizer > compost. In comparison to the control, it was evident that treatment T5 greatly boosted weight yield by 44%, after which application T4 (compost @ 15 t ha⁻¹) by 40%. In comparison to the baseline (control), the application T3 (compost @ 10 t ha⁻¹) has likewise greatly increased plant mass yield 2.5-ton ha⁻¹ (Fig 2).

According to Brown and Cotton (2011), applying compost to soils enhances the concentration of plant-available micronutrients in wheat plants. Fertilized soils demonstrated higher levels of micronutrients than traditional soils. Not every plant has access to every nutrient at once. They are long-lasting yet release gradually over time. Seran and associates (2010). The partial immobilization of essential nutrients can be attributed to the diverse range of binding mechanisms

and varying affinity levels within the organic matrix. In alkaline or calcareous environments, Iron (Fe) deficiency is a prevalent constraint because the concentration of soluble Fe in the soil solution often drops below 10^{-15} M, which is insufficient for critical physiological functions. However, as revealed by Vandecasteele et al. (2013), the practices of compost offer an imperative source for these trace metals. The adoption of composted organic matter (OM) elevates the soil with a diversity of specific and non-specific ligand sites. These functional groups (sites) meaningfully expand the soil's sorption potential and buffer the readiness of micronutrients, effectively alleviating the restrictions typically located in high-pH soil systems. This correlation between organic additives and increased nutrient conservation capacity is additionally supported by the insights of Vaca-Paulin et al. (2006).

Conclusion

These present investigations confirm that incorporating 15 t ha^{-1} of diverse-source organic compost (T4) significantly streamlines the wheat productivity (yield) and micronutrient bioavailability. Utilizing ammonium bicarbonate-diethylenetriaminepentaacetic acid (A-B DTPA) and wet digestion methods, findings reveal that T4 reached the maximized soil and plant Cu, Zn, and Fe concentrations, followed closely by the 10 t ha^{-1} rate (T3). Agronomically, T4 triggered a 40% yield increase and improved all growth parameters, including a 6.9% rise in 1000-grain weight. Statistical validation via RCBD and LSD ($p < 0.05$) supports compost as a vital amendment for enhancing nutrient uptake and sustainable crop performance in high-pH soils.

Acknowledgement

The author (s) acknowledge the Institute of Soil and Environment Sciences, PMAS Arid Agriculture University, for providing the technical and expert support in conducting the present study.

Author(s) Contribution

Latif, N. Conducted study in the field and compiled the data, S.M.H. Naqvi helped in data analysis, preparing manuscript, M.U. Rafiq helped in field experimentation.

Conflict of Interest:

There is no conflict of interest between the author(s) of the manuscript.

Ethical Approval

The author obtained approval from the institution's Research Ethics Board to conduct the study. Yet, there was no endorsement number to that effect.

Data Availability:

Documented data in this study will be accessible upon request to the corresponding author

Funding

The author(s) found no financial support from any financial institution.

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Novelty Statement

This study is among the first to unravel the dynamic transformations of micronutrient speciation during the composting process and link these changes directly to wheat growth and yield performance. In contrast to previous studies that chiefly centered on total nutrient concentrations, this research highlights the bioavailability that depends on micronutrient speciation, thus providing a process-based understanding of how compost quality regulates nutrient acquisition and crop productivity. The conclusions highlight the pivotal role of micronutrient speciation in formulating nutrient-efficient compost creation, offering newly identified pathways for sustainable soil fertility regulation and maximized wheat production.

References

- Ahmad R., M Naveed, M Aslam, ZA Zahir, M Arshad (2008). Economizing the use of nitrogen fertilizer in wheat production through enriched compost. *Renew Agri Food Sys* 23(3).
- Amlinger F, S Peyr, J Geszti, P Dreher, W Karlheinz, S Nortcliff (2007). Beneficial effects of compost application on fertility and productivity of soils. Literature Study, Federal Ministry for Agriculture and Forestry Envi and Water Management, Austria.
- Antil RS, D Raj, RP Narwal, JP Singh (2013). Evaluation of maturity and stability parameters of composts prepared from organic wastes and their response to wheat. *Was Bio Valo* 4(1): 95-104.
- Bajpai RK, SK Upadhyay, BS Joshi, RS Tripathi (2002). Productivity and economics of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system under integrated nutrient supply systems. *Ind J Agr* 47: 20-25.
- Bedada W, E Karlun, M Lemenih, M Tolera (2014). Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. *Agri Eco Env* 195: 193-201.
- Bernal MP, JA Alburquerque, R Moral (2009). Composting of animal manures and chemical criteria for compost maturity assessment. A review *Bior Tech* 100(22): 5444-5453.
- Brown S, M Cotton (2011). Changes in soil properties and carbon content following compost application: results of on-farm sampling. *Com Sci Util* 19(2): 87-96.
- Goyal S, SK Dhull, KK Kapoor (2005). Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bior Tech* 96(14): 1584-1591.
- Hanajima D, Y Fukumoto, K Suzuki, T Osada, K Kuroda, Y Fukumoto, T Yasuda, K Haga (2006). Reduction of nitrous oxide emission from pig manure composting by addition of nitrite-oxidizing bacteria. *Env Sci Tech* 40(21): 6787-6791
- Jordao CP, CC Nascentes, PR Cecon, RLF Fontes, JL Pereira (2006). Heavy metal availability in soil amended with composted urban solid wastes. *Env Mon Ass* 112(1-3): 309-326.
- Madeleine I, S Peter, T Tim, V Tom (2005). Agrodok no. 8: The preparation and use of compost. Agromisa Foundation, Wageningen.
- Memon M, GM Jamro, NN Memon, KS Memon, MS Akthar (2012). Micronutrient availability assessment of Tomato grown in taluka Badin, Sindh. *Pak J Bot* 44(2): 649-654.
- Mengel K, EA Kirkby, H Kosgarten, T Appel (2001). *Principles of Plant Nutrition*. Kluwer Academic Publishers, Dordrecht, The Netherlands
- Nazakat N., MS Nawaz, NM Cheema., MA Khan (2012). Zinc and Iron application to optimized seed yield of Mustard. *Pak J Agri Res* 25 (1): 28-33.
- Nazif W, S Parveen., I Saleem (2006). Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). *J Agri Bio Sci* 1(2): 35-40
- Nisar A, M Rashid, AG Vase (1996). Fertilizer and their use in Pakistan. *Planning Commission, NFDC. Govt of Pakistan*, 45.
- Partanen P, J Hultman, L Paulin, P Auvinen, M Romantschuk (2010). Bacterial diversity at different stages of the composting process. *BMC Microbiology*, 10(1): 94
- Rashid A. (1986). Mapping zinc fertility of soils using indicator plants and soils analyses. PhD Dissertation, University of Hawaii, HI, USA.

- Rehman H, T Aziz, M Farooq, A Wakeel, Z Rengel (2012). Zinc nutrition in rice production systems. *Plant and Soil*. 361: 203–226.
- Sarwar G (2005). Use of compost for crop production in Pakistan. Ph.D. Dissertation (Published) Ökologie und Umweltsicherung. Universität Kassel, Fachgebiet Landschaftsökologie und Naturschutz, Witzenhausen, Germany
- Seran TH, S Srikrishnah, MMZ Ahamed (2010). Effect of different levels of inorganic fertilizers and compost as basal application on the growth and yield of onion (*Allium cepa* L.). *The J Agri Sci* 5(2): 64-70.
- Shaheen A (2016). Characterization of eroded lands of Pothwar plateau, Punjab, Pakistan. *S J Agri* 32(3), 192-201
- Soltanpour PA, AP Schwab (1977). A new soil test for simultaneous extraction of macro-and micro-nutrients in alkaline soils. *Comm S S Pl Ana* 8(3): 195-207
- Uriah LA, U Shehu (2014). Environmental risk assessment of heavy metals content of municipal solid waste used as organic fertilizer in vegetable gardens on the Jos Plateau, Nigeria. *Amer J Env Prot* 3(6-2): 1-13
- Vaca-Paulin, R, MV Esteller-Alberich, J Lugo-De La Fuente, HA Zavaleta-Mancera (2006). Effect of sewage sludge or compost on the sorption and distribution of copper and cadmium in soil. *Waste Manag* 26(1): 71-81.
- Vandecasteele B, K Willekens, A Zwertvaegher, L Degrande, FMG Tack, G Du Laing (2013). Effect of composting on the Cd, Zn and Mn content and fractionation in feedstock mixtures with wood chips from a short-rotation coppice and bark. *Waste Manag* 33(11): 2195-2203.