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Comparative Assessment of Vermicompost and Chemical Fertilizers on Maize Yield and Nutritional Quality

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Abstract **Original Research Article**

This research evaluates the impact of vermicomposting using municipal solid waste (MSW) mixed with poultry litter (PL) or farmyard manure (FYM) on soil fertility and maize growth (Zea mays). At PMAS Arid Agriculture University in Rawalpindi, a greenhouse experiment was conducted using a completely randomized design (CRD). The treatments comprised combinations of municipal solid waste with poultry litter and farmyard manure, applied with and without half of the recommended NPK fertilizer rates. The study found that integrating vermicompost with lower NPK fertilization significantly improved soil characteristics. The organic matter content, the availability of nutrients, particularly nitrogen, phosphorus, and potassium, and the ability to distinguish between different amounts of micronutrients, including iron, zinc, copper, and manganese, were all improved. These soil improvements resulted in notable increases in maize growth metrics, such as plant height, root and shoot biomass, and overall yield. This study suggests a sustainable and efficient way to improve soil fertility and maize crop productivity by combining vermicompost with reduced NPK fertilizer rates, thus promoting integrated nutrient management techniques.
Keywords: Vermicompost, Maize, Earthworm, Soil, Nutrient Uptake, Poultry Litter, Farmyard Manure.

INTRODUCTION

Vermicomposting is the process of breaking down organic waste with earthworms to produce vermicast, a high-quality end product. Because of its great nutritional value and ability to condition soil, vermicompost is considered a significant organic fertilizer. In addition to enhancing the soil's drainage and other physical qualities, vermicompost provides nutrients that dissolve in water. Organic wastes including leftover food, beverage residues, scrap paper, crop residues, farmyard manure, and yard trimmings are all consumed by earthworms. These wastes are then converted into usable products, such as worm castings, vermicast tea, and worm meal. Vermicompost serves as an organic fertilizer and biological control agent, eliminating a range of plant diseases brought on by pests and soil-bome plant diseases. Vermicompost can be used to improve soil nutrient status (Thakur *et al.*, 2021). Vermicomposting is the process of "bioxidation and stabilization of organic waste" that is made possible by mesophilic bacteria and earthworms. Earthworms consume agricultural waste, which reduces its volume by 42% to 62% when the right conditions are met. Along with immobilized microorganisms, vermicompost is abundant in vitamins, growth hormones, lipase, cellulase, and chitinase, as well as macro and micronutrients (Fatima *et al.*, 2024; Olle, 2019).

Applying vermicompost can enhance beneficial microbial growth, increase crop yields, improve soil structure, and elevate plant secretion. For plants with extended growing seasons, additional fertilization using bio-humus is adequate, making inorganic fertilizers unnecessary. Being 100% natural, vermicompost is ideal for organic farming (Sultana, 2021; Ullah *et al.*, 2024b).

Waste management has always been vital for a sustainable society, yet the growing volume and concentration of waste produced by today's market pose serious global challenges, threatening both ecosystems and public health (Kakati *et al.,* 2022). Vermicomposting is globally employed to convert various organic materials into environmentally friendly products because of its sustainable nature. Many elements influence the effectiveness of vermicomposting, including the type of earthworms chosen, the makeup of the substrate, the surrounding environment, and the aeration system used during the procedure (Lim *et al.,* 2016a).

A significant environmental problem facing today's rising economies is the generation of municipal solid waste (Waseem *et al.,* 2023). The World Bank estimates that by 2050, the amount of municipal solid waste (MSW) worldwide will have increased from 2011 million tonnes in 2017 to 3500 million tonnes (Kaza *et al.,* 2018). In managing municipal solid waste, cities and urban organizations play a crucial role. Composting and vermicomposting are sustainable techniques that are gaining popularity in addition to traditional methods including open dumping, sanitary landfills, and burning. Every municipal corporation keeps track of the substantial amount of organic and biodegradable trash produced every day (Sequeira and Chandrashekar, 2015).

Vermicomposting and composting are two methods of processing municipal solid waste that support environmental and socioeconomic sustainability by recovering nutrients for plant development (Srivastava *et al.,* 2020).

Vermicomposting offers a cost-effective way to improve waste management, which lowers the cost of garbage disposal, transportation, and collection (Haidri *et al.,* 2024). This development, which focuses on reducing resource loops and promoting sustainability, exemplifies the ideas of a circular economy. It's critical to look into potential alternatives and assess the scientific effects of present waste management techniques as noted by Srivastava *et al.,* (2020). One major obstacle to circular waste management is addressing the recovery of organic waste in metropolitan areas. By reintroducing organic matter into the soil, this method seeks to establish a closed loop that preserves natural resources and minimizes the impact on the environment (Ghisellini *et al.,* 2016). The primary source of vermicompost, like humus, is the breakdown and stabilization of organic matter as detailed by (Doan *et al.,* 2015).

Poultry waste is high in nutrients, which can cause environmental issues such as eutrophication and phytotoxicity if used in excess (Fatima *et al.,* 2024). These issues can be lessened and these nutrients stabilized by using earthworms (Yuvaraj *et al.,* 2019). Poultry manure requires safe and cost-effective disposal methods due to its high organic contents (Beohar and Srivastava, 2011). When compared to other animal manures, poultry litter contains more protein and phosphorus. Using old poultry litter for vermicomposting is recommended to reduce interference from inorganic salts, boost heat potential, and ensure worm survival (Patil *et al.,* 2012). Composting and vermicomposting successfully convert trash into bio-fertilizers, playing a significant role in cleaner production strategies, and they give practical methods for dealing with organic waste in the area (Ullah *et al.,* 2024a). Additionally, recovering useful organic compounds and restoring them to the soil is necessary(Lim *et al.,* 2016b). Farmyard manure is commonly utilized as an organic fertilizer, despite its limited availability. Vermicomposting provides a practical answer by facilitating the successful recycling of huge amounts of agricultural waste, therefore tackling the accessibility concerns associated to farmyard manure (Gupta *et al.,* 2019). This research study has the following objectives 1. To generate vermicompost using municipal solid waste 2. To evaluate the impact of using vermicompost made from municipal solid waste on soil and plants.

MATERIAL AND METHODS

EXPERIMENTAL SETUP

The Biogas Unit on campus was used for the experiment at PMAS-Arid Agriculture University in Rawalpindi. The experimental arrangement was located in the biogas unit's storage room, making it a perfect location for vermicomposting. The ideal temperature and ventilation were present for earthworm cultivation.

COLLECTION OF EARTHWORM

Eisenia fetida, also known as composting worms or red wigglers, were the particular earthworm species used in the vermicomposting process. These worms were sourced from a village farm in the Attock region located. Interestingly, the earthworm species employed in the vermicomposting process at this farm were originally imported from Australia.

COLLECTION OF ORGANIC WASTES

Three different types of organic wastes were used for this research purpose, these includes municipal solid waste, farmyard manure and poultry litter.

Municipal Solid Waste

Various sources of municipal solid waste were gathered from different locations, including vegetable and fruit shops, household kitchen waste bins, and the university garden. The collected waste consisted of a variety of organic materials such as vegetable scraps (tomatoes, cucumber, potatoes, brinjal, mint, coriander, okra, etc.), fruit peels and leftovers (melons, bananas, watermelons, mangoes, peaches, apples, plums, etc.), and green manure like grass clippings. Once all the organic materials were collected, they were crushed into small pieces in preparation for the vermicomposting process.

Farmyard Manure

The farmyard manure used in the experiment was obtained from the university farm, which is located within the campus premises. However, the fresh farmyard manure was found to be detrimental to the earthworms. To make it suitable for vermicomposting, the farmyard manure was spread out for air drying for a period of 15-20 days. This process helped in removing harmful gases and reducing excessive heat. After drying, the farmyard manure was carefully pulverized into tiny pieces to give the earthworms the best possible diet.

Poultry Litter

The poultry litter used in this study originated from a poultry farm located across from the university campus. In order to ensure uniformity, the litter was exposed to sunlight for four days until its moisture content reached 40%. Before beginning the vermicomposting phase, the litter underwent a 15-day pre-composting stage utilizing the windrow method. In order to maintain the moisture level above 50%, efforts were made during the 90-day research. In order to improve the efficacy of the earthworms participating in the vermicomposting process and the process's overall efficiency, this was crucial for establishing ideal conditions for them.

VERMICOMPOST PREPARATION

The study used three plastic baskets, each with a small drainage hole at the bottom and a 5-kg capacity for organic waste. Each of the three different treatments was duplicated three times. Using the designated treatments, a 1:1 combination of organic materials was stacked in the plastic baskets after a pre-decomposition period of 15 to 20 days, following the method described by (Bhat *et al.*, 2014).

The organic components were rotated every day for the first 15 to 20 days in order to eliminate excess heat, harmful compounds, and volatile gasses. Each plastic bucket was gradually filled with 150 young Eisenia fetida worms following the pre-decomposition of the organic waste. Watering was done every day to keep the moisture level at 60%, which encouraged the best worm activity (Fatima *et al.*, 2024). To prevent moisture loss, insect infestations, and other interruptions, jute was used to cover the plastic buckets.

At 15–20 day intervals, counts of adult earthworms, cocoons, and new hatchlings were conducted. The organic feed materials were processed by the earthworms' alimentary canal, transforming them into loose granules resembling fine-textured soil. As the experiment approached 50-60 days, the color of the organic materials changed to dark brown or black, indicating successful decomposition. As we approached the conclusion of the experiment, the activity of earthworms decreased, and new hatchlings and cocoons were removed through sieving. The study concluded by assessing the outcomes and results achieved through the vermicomposting process.

HARVESTING AND SIEVING OF VERMICOMPOST

After the vermicompost preparation phase, water sprinkling was stopped approximately a week ago, and the compost was arranged into a heap to enhance earthworm performance. The earthworms responded by moving downwards and congregated at the bottom of the heap. The fully matured vermicompost was collected from the top layer.

Subsequently, the vermicompost was shaped into forms and left to air dry. It was then placed in plastic bags for physiochemical examination. To separate the earthworms from the vermicompost, a manual process involving hand sorting and picking the worms directly from the vermicompost was used.

The vermicompost was acceptable to air dry for about 2-3 days. Once it was sufficiently dried, it underwent sieving using a 4 mm sieve. This sieving process effectively separated any un-decomposed material, as well as cocoons and new hatchlings from the vermicompost.

TREATMENTS

Three different vermicomposts were created using various organic wastes through three distinct treatments.

Three Different Vermicompost Treatments

Essentially, three distinct treatments were employed to prepare vermicompost using three different organic materials. Municipal Solid Waste served as the common component in all three treatments, while farmyard manure and poultry litter were added as supplementary sources to enhance the decomposition process of the municipal solid waste. Each treatment incorporated a mixture of organic materials in a 1:1 ratio, comprising 50% municipal solid waste and 50% other waste materials, tailored to each specific treatment.;

T1: Municipal Solid Waste (Control)

T2: Municipal Solid Waste + Poultry Litter (1:1)

T3: Municipal Solid Waste + Farmyard Manure (1:1)

GREENHOUSE EXPERIMENT

At the campus of PMAS-Arid Agriculture University in Rawalpindi, a 60-day greenhouse pot experiment was carried out. The primary objective was to assess the impact of vermicompost-amended soil on plant micronutrient uptake and concentrations. Soil samples were collected from the university grounds, sieved to a particle size of 2mm, and then filled into individual pots at a quantity of 5kg per pot. This setup allowed for the evaluation of seven different treatments, each replicated three times to ensure reliable results.

Treatments

T1: Control
T2: N, P, K (Recommended Dose)
T3: MSW @ 25g / pot
T4: MSW + PL @ 25g / pot
T5: MSW + FYM @ 25g / pot
T6: MSW + ½ NPK @ 25g / pot
T7: MSW + PL + ½ NPK @ 25g / pot
T8: MSW + FYM + ½ NPK @ 25g / pot

RESULTS AND DISCUSSIONS

Effect of vermicompost on different parameters

pH in Vermicompost

Mature vermicompost typically exhibits a pH range of 6 to 8. Throughout decomposition, it undergoes pH fluctuations, beginning as quite acidic and gradually becoming more neutral as the organic materials decompose. In Figure 1 analysis revealed a higher pH in the control treatment, while the MSW+PL treatment demonstrated a lower pH. The conversion of nitrogen and phosphorus into nitrates, nitrites, and orthophosphates is influenced by pH, which is a critical factor in nutrient availability. The transition from alkaline to neutral or acidic pH may be explained by this process as well as the conversion of organic molecules into intermediate organic acids (Tejada and Benítez, 2020). Vermicompost made from deciduous tree leaves showed a slightly acidic pH ranging from 6.2 to 6.3 (Fatima *et al.*, 2024).

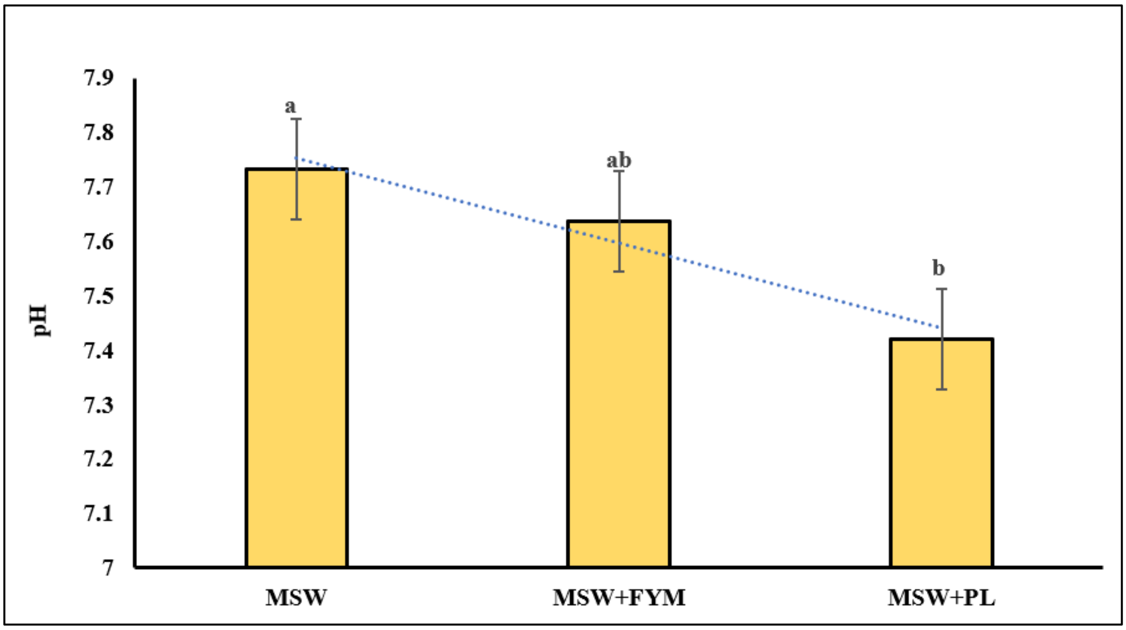

Figure 1: Changes in pH contents during vermicomposting

EC of vermicompost

Excessive soluble salt absorption can pose risks to plants. The electrical conductivity (EC) of different vermicompost types varied between 2.6 and 4.1 dS/m. Reduced electrical conductivity resulted from mineral leaching during the vermicomposting process. As shown in Figure 2, the mature vermicompost from T1 (Control) had the highest EC at 3.7 dS/m, followed by T2 at 3.5 dS/m and T3 at 2.57 dS/m. This indicates a good quality of the vermicompost. Yuvaraj *et al.*, (2019) designated that the elevation in soluble salt levels, driven by bacteria and worms, has led to increased EC values in the final vermicompost. This rise in EC signifies the process of waste mineralization. As organic materials decompose, ions such as ammonium, phosphate, potassium, nitrate, and calcium are generated, resulting in higher EC levels (Fatima *et al.*, 2024).

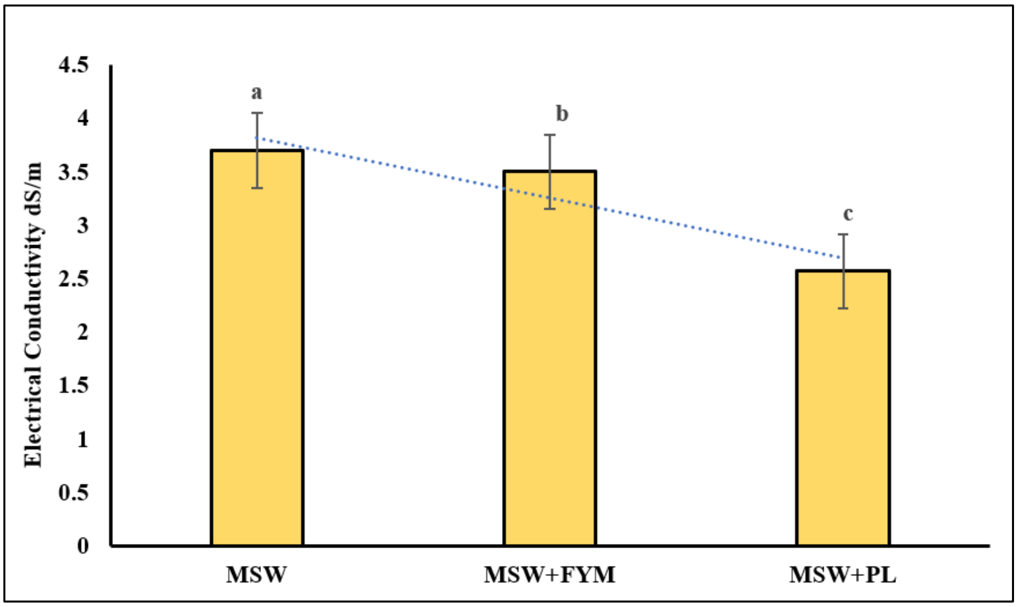

Figure 2: Changes in EC Contents during vermicomposting

Total Nitrogen Contents in Vermicompost

Figure 3 illustrates the total nitrogen content found in different vermicomposts. It shows that MSW+PL had the highest nitrogen level at 3.16%, followed by MSW+FYM with 2.7%. The minimum nitrogen content recorded was 1.7% in MSW. The findings show that total nitrogen levels rose from the pre-composting phase to maturity. Earthworms play a crucial role in promoting nitrogen mineralization and enhancing nitrogen levels in vermicompost (Mistry *et al.*, 2015). The initial loss of nitrogen as ammonia led to a decrease in total nitrogen (TN) content, which is influenced by the type of material and its carbon-to-nitrogen (C: N) ratio (Kaur *et al.*, 2024).

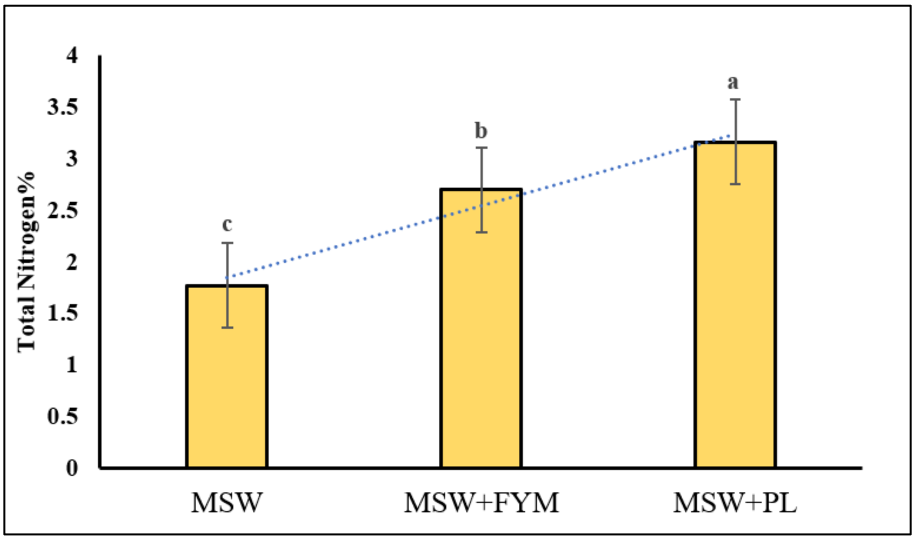

Figure 3: Changes in Total Nitrogen Contents during Vermicomposting

Total Phosphorus Contents in Vermicompost

In the maturity stage, the proportion of extractable phosphorus varied significantly among the treatments shown in Figure 4. With a level of around 1.2%, the MSW+PL treatment had the highest extractable phosphorus, followed by the MSW+FYM treatment at roughly 0.8%. In contrast, the MSW therapy had the lowest level—nearly 0.3%. A statistical study showed that the treatments differed significantly from one another. According to Malińska *et al.,* (2016) elevated phosphorus levels in processed vermicompost may be associated with reduced body weight and fewer carbon dioxide emissions required to decompose labile organic matter components. Swarnam *et al.,* (2016) determined that When combined with phosphate-solubilizing bacteria, the earthworm-derived phosphatase enzyme acts as the essential catalyst to convert phosphorus from feedstock into a form that can be used (Fatima *et al.*, 2024).

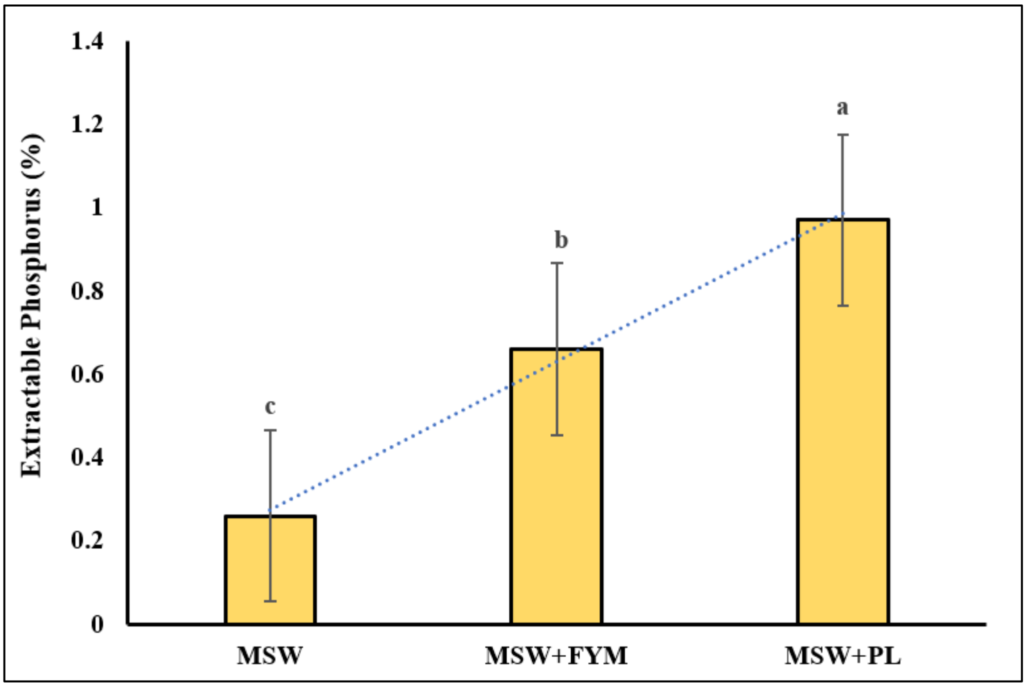

Figure 4: Changes in Total Phosphorus Contents during vermicomposting

Total Potassium Contents in Vermicompost

The percentage of potassium in each form of vermicompost is shown in Figure 5. The MSW+PL compost had the highest potassium concentration, at 4.4%, followed by MSW+FYM at 3.15%. With a potassium level of just 1.7%, the MSW therapy had the lowest level. The percentages of extractable potassium varied significantly amongst the treatments as well. The MSW+PL treatment had the highest extractable potassium, approximately 5%, followed by MSW+FYM at nearly 3%, while MSW reported the lowest at around 2%. Statistical analysis indicated significant differences among the treatments. Maharjan *et al.,* (2024) determined that the kind of waste material utilized in vermicomposting affects the highest potassium content. High potassium levels in vermicompost are caused by significant mineralization resulting from microbial activity in the earthworm's digestive system (Ummer *et al.,*).

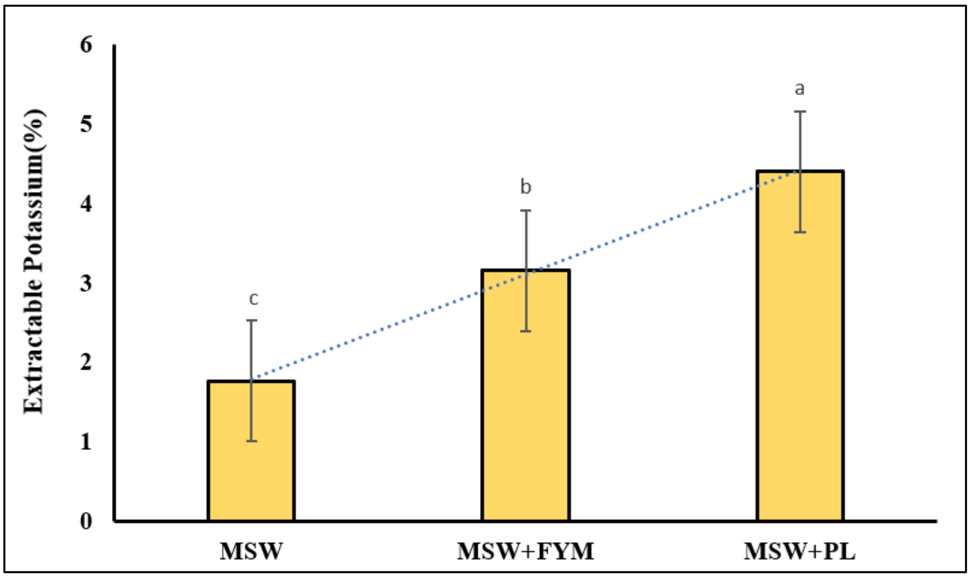

Figure 5: Changes in Total Potassium Contents during vermicomposting

Iron Contents in Vermicompost

In Figure 6 the iron content in vermicompost varies from 3.8 mg/kg to 8.83 mg/kg shown in Figure 6. Among these variations, the highest recorded iron content of 8.83 mg/kg was determined in the MSW + PL, followed by MSW + FYM at 5.8 mg/kg. The lowest iron content, 3.8 mg/kg, was evaluated in the Control. The maximum Fe content of tree leaf's vermicompost might be due to the lower pH value in deciduous tree leaves' vermicompost. The researchers said that the high pH decreases the availability of Fe content (Moustafa *et al.*, 2021).

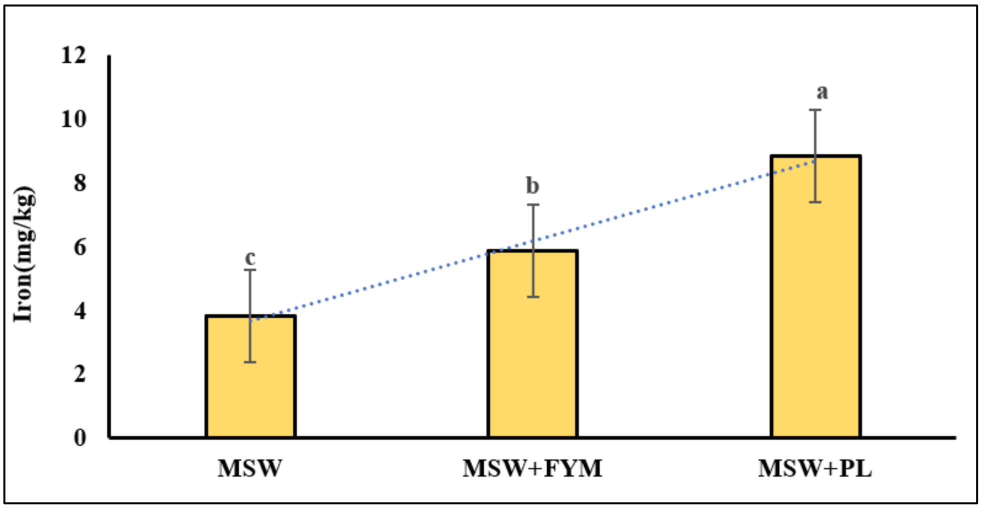

Figure 6: Changes in Iron Contents during vermicomposting

Zinc Contents in Vermicompost

The zinc levels in vermicompost range between 161.3 mg/kg and 187.3 mg/kg shown in Figure 7. The maximum zinc level recorded was 187.3 mg/kg in the MSW+PL sample, followed by 172.3 mg/kg in the MSW+FYM sample. The lowest zinc concentration revealed was 161.3 mg/kg in the control group. The maximum levels of total nitrogen, phosphorus, potassium, microbial activity, enzyme activity, and growth regulators might contribute to the increased zinc content in the leaves of vermicompost, serving as a micronutrient (Sharma and Garg, 2018).

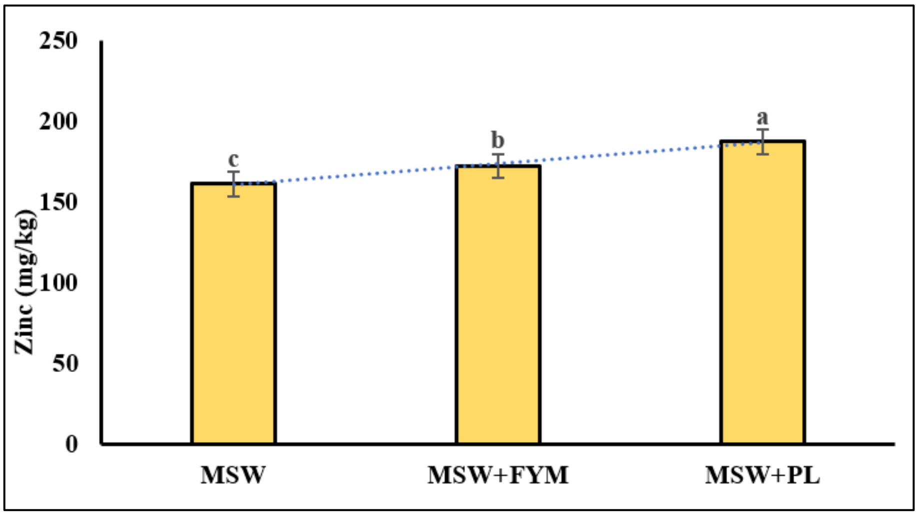

Figure 7: Changes in Zinc contents during vermicomposting

Copper Contents in Vermicompost

The copper levels in vermicompost range between 35 mg/kg and 45 mg/kg shown in Figure 8. The highest copper level recorded was 45 mg/kg in the MSW + PL mixture, while the MSW + FYM combination showed a copper content of 39.3 mg/kg. The lowest level, at 35 mg/kg, was found in the control group. Copper content progressively increased from the initial to the maturity stage. At maturity, the highest total copper content of 48.8 mg/kg was observed in T1 (50% Deciduous tree leaves + 50% Cow dung), probably resulting from the microbial degradation of organic material during composting, which enables the movement and accumulation of copper (Syarifinnur *et al.*, 2023; Ummer *et al.*,).

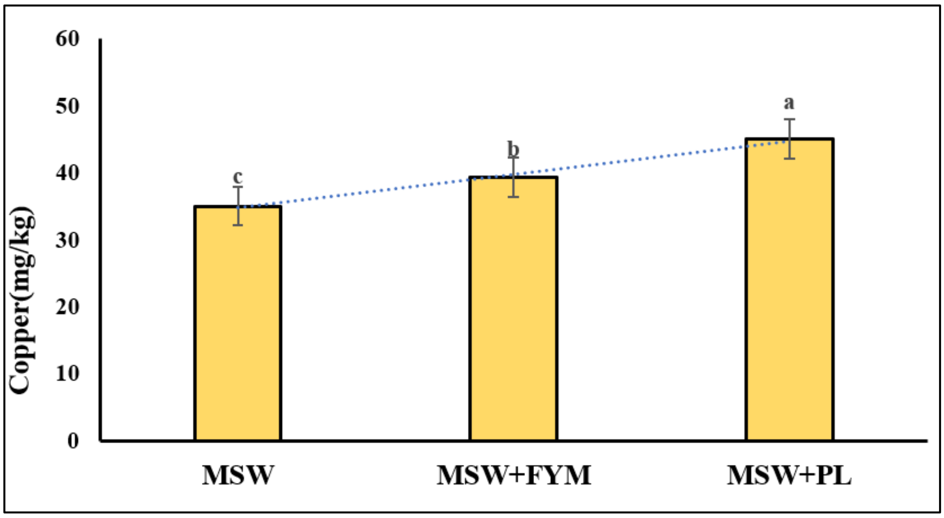

Figure 8: Changes in Copper Contents during vermicomposting

Manganese Contents in Vermicompost

Vermicompost's manganese content ranges from 257.6 mg/kg to 332 mg/kg shown in Figure 9. The highest manganese level, 257.6 mg/kg, was evaluated in the MSW+PL sample, while the MSW+FYM recorded 298.3 mg/kg. The control sample showed the lowest copper content at 332 mg/kg. The primary factors driving the increase in micronutrient levels are the breakdown of organic matter and mineralization. Additionally, reducing waste volume contributes to a concentration of trash, enhancing micronutrient content; the lowest level was found in the FYM (control) at 108.7 mg/kg (Sharma and Garg, 2018).

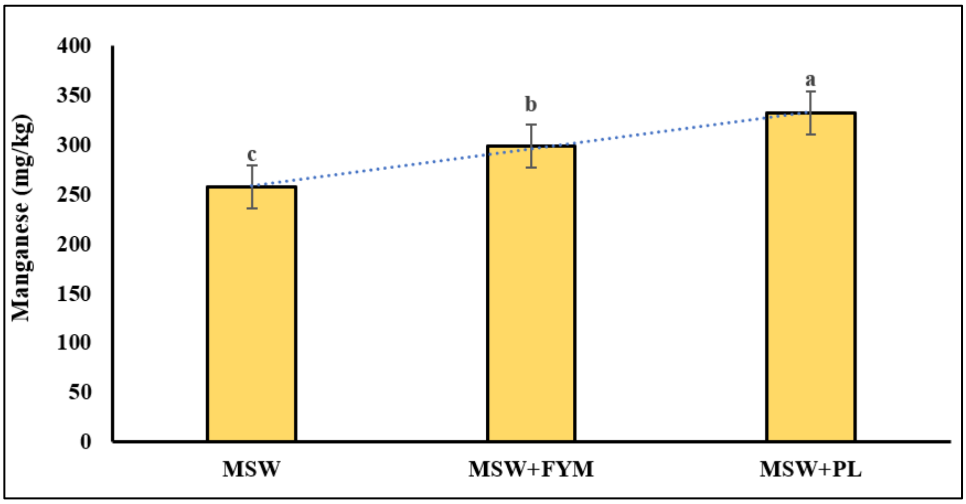

Figure 9: Changes in Manganese Contents during vermicomposting

GREENHOUSE EXPERIMENT

At the Pir Mehr Ali Shah Arid Agriculture University in Rawalpindi, a greenhouse pot experiment was carried out. The objective was to assess the impact of vermicompost-amended soil on plant micronutrient uptake and concentration. Soil obtained from the University of Arid Agriculture was sieved (2 mm) and added to pots at a 5 kg per pot capacity. This setup allowed for the implementation of eight distinct treatments, each replicated three times. The experiment spanned a duration of 60 days.

Soil analysis before sowing

Before maize planting, a preliminary physico-chemical analysis was conducted on the soil to understand its characteristics. The results classified the soil as silty clay loam. At first, the soil had a pH of 7.8 and an electrical conductivity (EC) of 0.32 dS/m. Additionally, the extractable potassium content was recorded at 127 mg/kg, and the available phosphorus content was found to be 8.24 mg/kg. Crucially, the pH and EC values remained within the acceptable limits, specifically below 8.5 and less than 4 dSm-1, signifying that the soil was neither overly alkaline nor saline. Additionally, the analysis showed that the extractable potassium level was sufficient, exceeding the 80 mg/kg threshold, while the available phosphorus content was found to be inadequate at 10 mg/kg.

Table 1: Physico-chemical analysis of soil used for growing maize crop

Soil Parameter	Value
Texture	Silty Clay Loam
pH	7.8
EC (dS m^{-1})	0.32
Organic matter	0.45
Available P(mg/kg)	8.24
Extractable K (mg/kg)	127
Total N(mg/kg)	4.02
Zn (mg/kg)	0.74
Fe (mg/kg)	2.24
Mn (mg/kg)	1.82
Cu (mg/kg)	0.16

Effect of Vermicompost Application on Maize Crop

Plant height (cm)

Different vermicompost mixtures, including MSW, MSW+FYM, and MSW+PL, were generated. Plant height significantly influences yield for any crop and is a vital agronomic factor. According to the collected data, the incorporation of vermicompost, whether applied individually or alongside mineral fertilizers, notably elevated plant height. Across the implemented treatments, plant heights exhibited a range spanning from 63.2 cm to 99.8 cm. Notably, the results revealed that the highest recorded plant height of 99.8 cm was achieved in the MSW+FYM+1/2NPK@25g/pot treatment during the pot experiment. Conversely, the lowest plant height value of 63.2 cm was observed in the control.

The relationship between NPK and Vermicompost was discovered significant. The maximum Plant Height (cm), was (67,168, and 172 cm), Number of leaves per plant(7, 13, and 15), found in T9 (NPK @ 100% + Vermicompost @ 100%) had a similar effect of Vermicompost on growth parameters were found in the positive application of Vermicompost on growth parameters have also been reported by Rao *et al.*, (2020) and minimum (41,109 and 111 cm) and (3, 5 and 7) was recorded in T_1 (NPK @ 100% + Vermicompost @ 100%) respectively. Cereal crop growth can be improved by the interaction of these components. A balanced application of NPK fertilizers provides vital nutrients for plant growth (Kumar *et al.*, 2018).

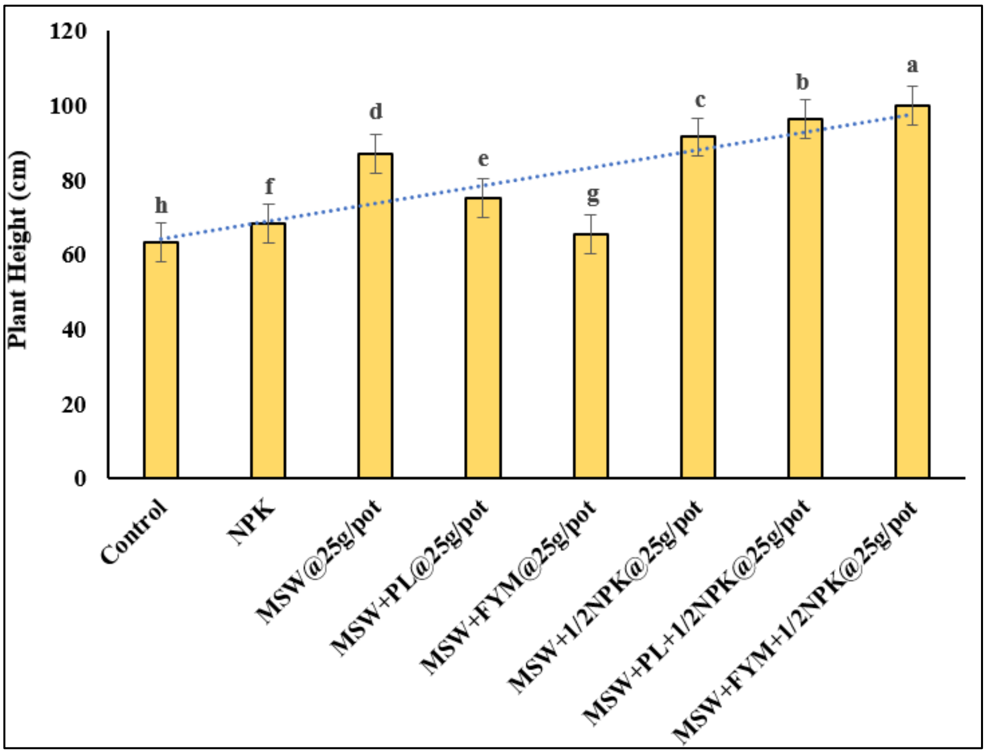

Figure 10: Effects of vermicompost on Plant Height in maize

Root Weight

Plant fresh weight is important for fodder purposes. The fresh root weight showed a variable range under the applied treatments ranging from 17.1 to 34.5 g as shown in Figure 11. The highest range for root fresh weight was 34.5g recorded in MSW+FYM+1/2NPK@25g/pot followed by 32.5g in MSW+PL+1/2NPK@25g/pot. The lowest range for root fresh weight was 17.1g recorded in Control. The dry root weight showed a variable range under the applied treatments ranging from 8.55 to 17.25 g as shown in Figure 12. The highest range for root dry weight was 17.25g recorded in MSW+FYM+1/2NPK@25g/pot followed by 16.25g in MSW+PL+1/2NPK@25g/pot. The lowest range for root fresh weight was 8.55g recorded in Control. Vermicompost raised root growth by increasing microbial activity and improving soil health. Furthermore, the vermicompost application raised the parameters related to maize yield (Kmeťová and Kováčik, 2014).

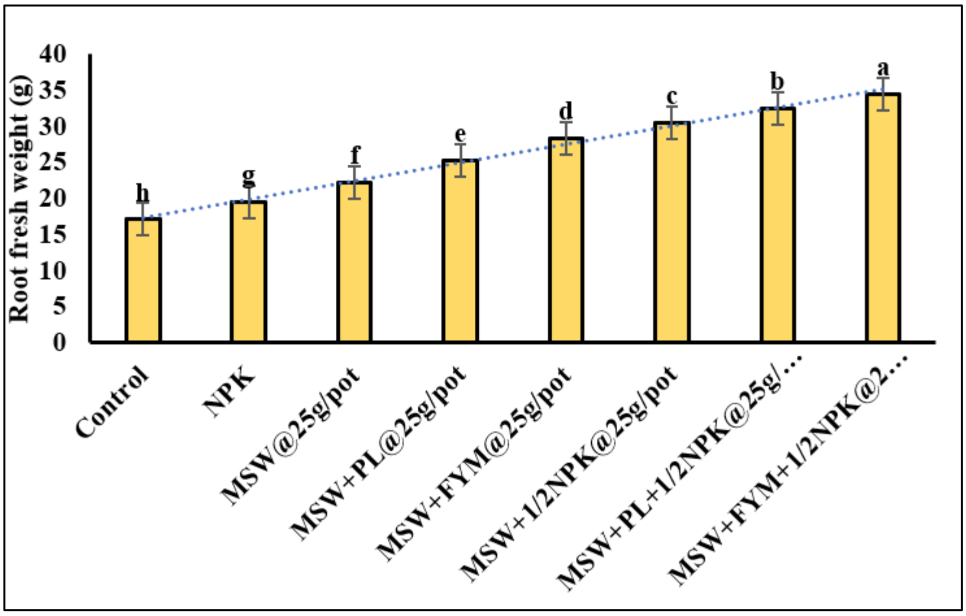

Figure 11: Effects of vermicompost on Root fresh weight in maize

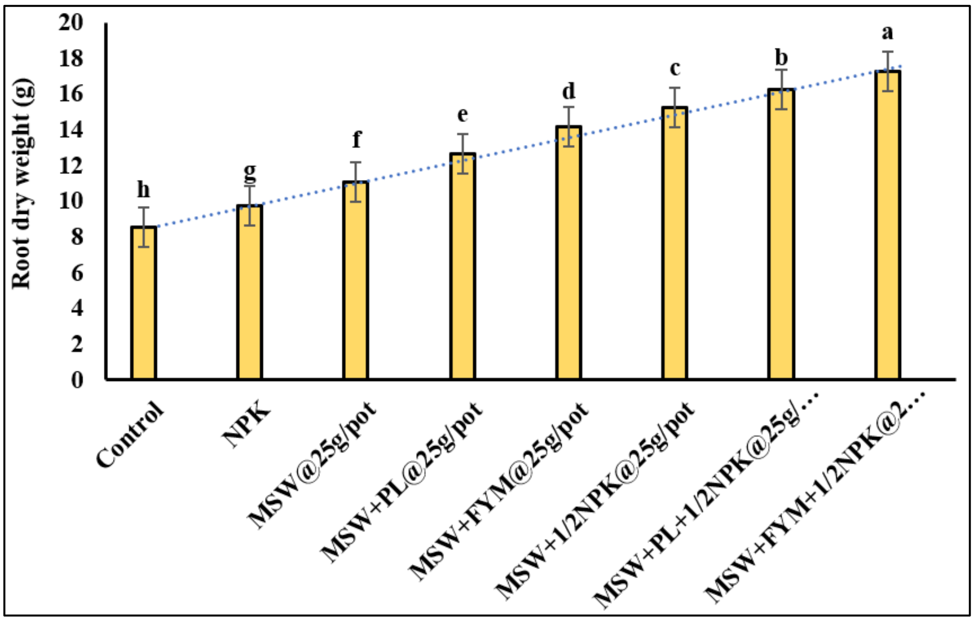

Figure 12: Effect of vermicompost on dry root weight in maize

Shoot Weight

Fresh shoot weight showed a variable range under the applied treatment, ranging from 32.96 to 52.6 g, as shown in Figure 13. The maximum plant fresh shoot weight of 52.6 g was recorded in MSW+FYM+1/2NPK@25g/pot, followed by 51.06 g in MSW+PL+1/2NPK@25g/pot. The minimum shoot weight of 32.96 g was noted in the Control. The other treatments had significant differences from each other. Dry shoot weight showed a variable range under the applied treatment, ranging from 16.48 to 26.3 g, as shown in Figure 14. The maximum plant dry shoot weight of 26.3 g was recorded in MSW+FYM+1/2NPK@25g/pot, followed by 25.53 g in MSW+PL+1/2NPK@25g/pot. The minimum shoot weight of 16.48 g was noted in the Control. The other treatments had significant differences from each other. These findings were similar to the researchers (Aslam and Ahmad, 2020).

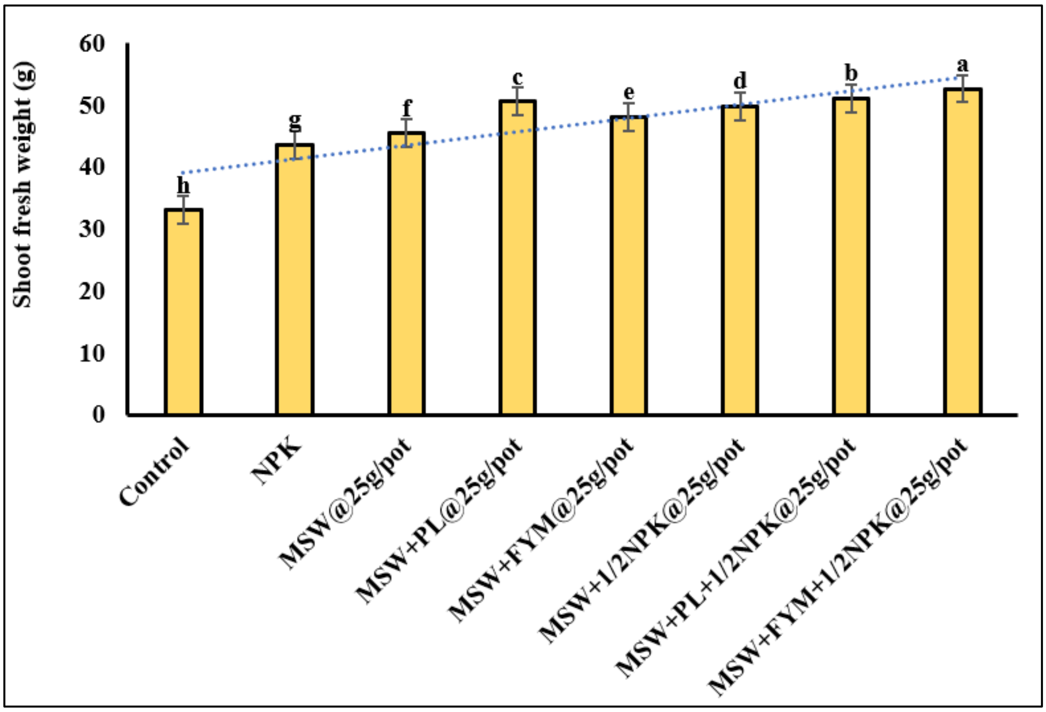

Figure 13: Effects of vermicompost on fresh shoot weight in maize

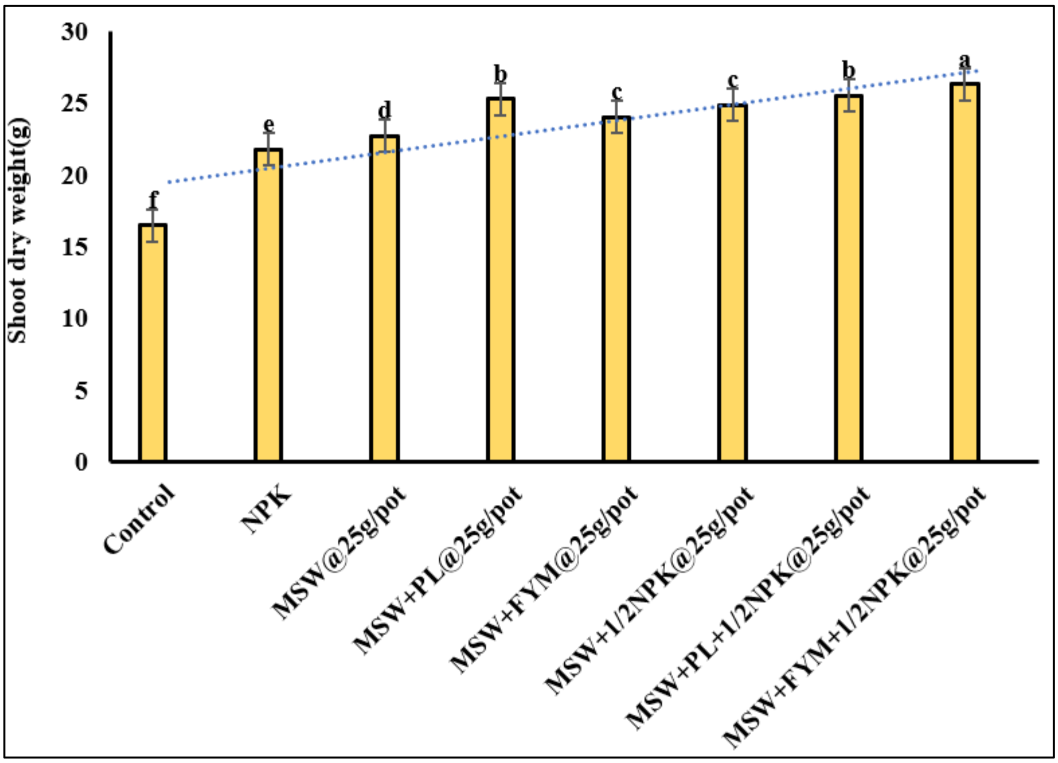

Figure 14: Effects of Vermicompost on dry shoot weight in maize

Total Nitrogen

In plants, the nitrogen content varies within the range of 0.52% to 1.64% in Figure 15. Among these variations, the highest nitrogen content, reaching 1.66%, was observed in the treatment involving MSW+FYM+1/2NPK@25g/pot. Conversely, the lowest recorded value of 0.52% was associated with the control. Microbial activity plays a pivotal role in making carbon, nitrogen, and phosphorus within microbial biomass accessible to plants (Malik, Marschner, & Khan, 2012). A recent study by Ananthi & Vennila (2023) suggested that combining farmyard and poultry manure with the recommended dose of inorganic fertilizer for fodder maize led to elevated nitrogen levels. Conversely, the lowest nutrient uptake was noted in plots where no nutrient application was carried out for the fodder maize.

The simultaneous application of inorganic fertilizers and organic manures increased the absorption of nutrients. This improvement may be explained by the maize plants' balanced nutrient availability, which produces a healthy soil environment. These favorable conditions subsequently boosted nutrient availability and the soil's water-holding capacity, resulting in improved growth and yield for the fodder maize crop(Ananthi and Vennila, 2023).

A key element essential for a plant's healthy growth is nitrogen. It is considered the most important factor in encouraging plant development. Nitrogen is a vital part of chlorophyll, the compound that provides plants with their green color. Organic materials used in vermicomposting can release nitrogen, potentially explaining the elevated nitrogen levels in vermicomposting samples. Additionally, earthworms add bodily fluids, mucus, and excretory secretions to the substrate, further boosting nitrogen content (Emendu *et al.*, 2021).

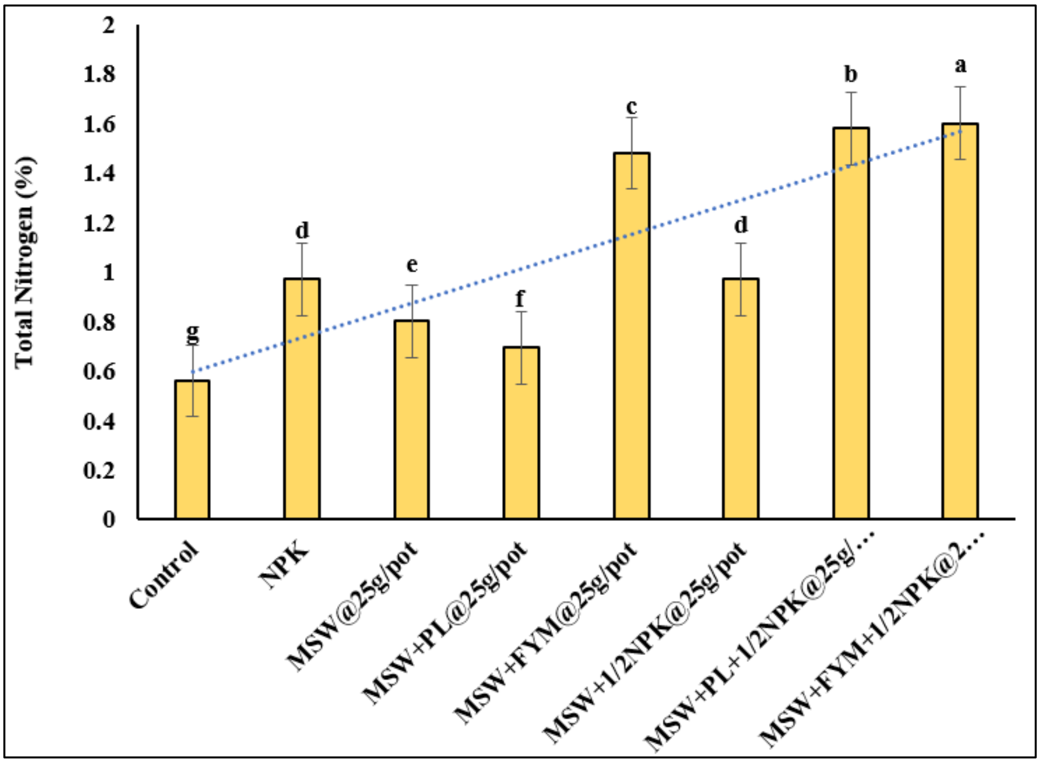

Figure 15: Effects of vermicompost on Total Nitrogen in maize

Total Phosphorus

Within the realm of plant composition, the phosphorus content spans a range of 0.28% to 0.69% in Figure 16. Among these variations, the highest phosphorus content, registering at 0.69%, was documented in the treatment involving MSW+PL+1/2NPK@25g/pot. Following closely, a phosphorus content of 0.68% was observed in the MSW+PL@25g/pot treatment, while the lowest value of 0.28% was attributed to the control.

Research by Tahir, Manzoor, Zafar, & Shehzad (2022) put forth that vermicomposting procedures contributed to an increase in soil organic matter content, consequently leading to higher concentrations of phosphorus, calcium, magnesium, and potassium. In a similar vein, Ananthi & Vennila (2023) reported that combining farmyard and poultry manure with the recommended dose of inorganic fertilizer for fodder maize resulted in elevated phosphorus levels. Conversely, the lowest nutrient uptake was noted in plots where no nutrient application was carried out for the fodder maize crop(Ananthi and Vennila, 2023; Tahir *et al.*, 2022).

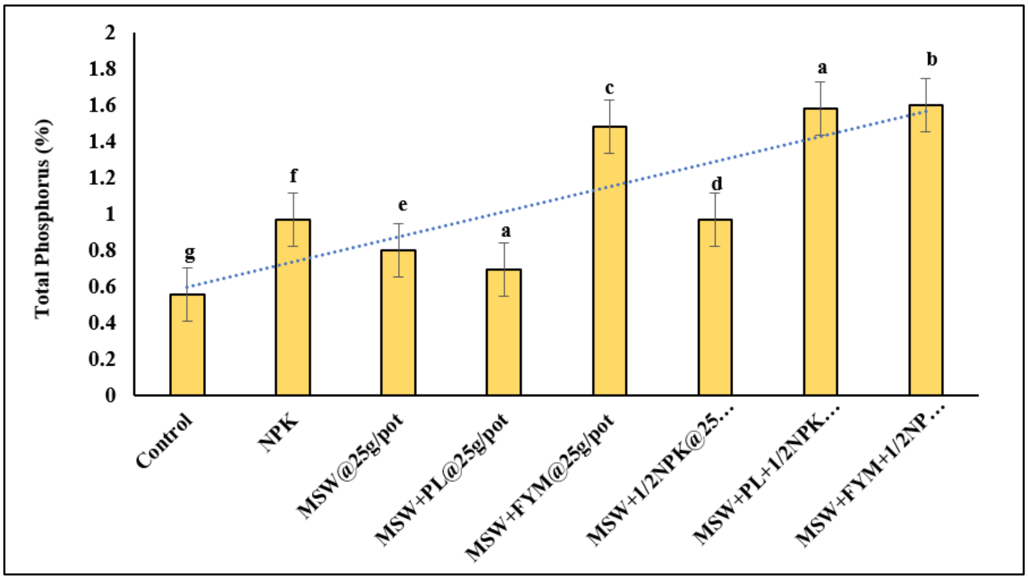

Figure 16:Effects of vermicompost on Total Phosphorus in maize

Total Potassium

In across plant specimens, the potassium content varies within a range of 0.41% to 0.96% in Figure 17. Among these divergences, the highest phosphorus content, reaching 0.96%, was documented in the treatment involving MSW+PL+1/2NPK@25g/pot. In a closely trailing sequence, a phosphorus content of 0.74% was observed in the MSW+PL@25g/pot treatment, while the lowest recorded value of 0.41% was attributed to the control.

Research by Tahir *et al.*, (2022) posited that vermicomposting processes contributed to heightened soil organic matter content, subsequently leading to increased concentrations of phosphorus, calcium, magnesium, and potassium. Correspondingly, Ananthi & Vennila (2023) noted that combining farmyard and poultry manure with the recommended dose of inorganic fertilizer for fodder maize cultivation resulted in elevated potassium levels. Conversely, the lowest nutrient uptake was observed in plots where no nutrient application was administered to the fodder maize crops (Devi and Khwairakpam, 2020).

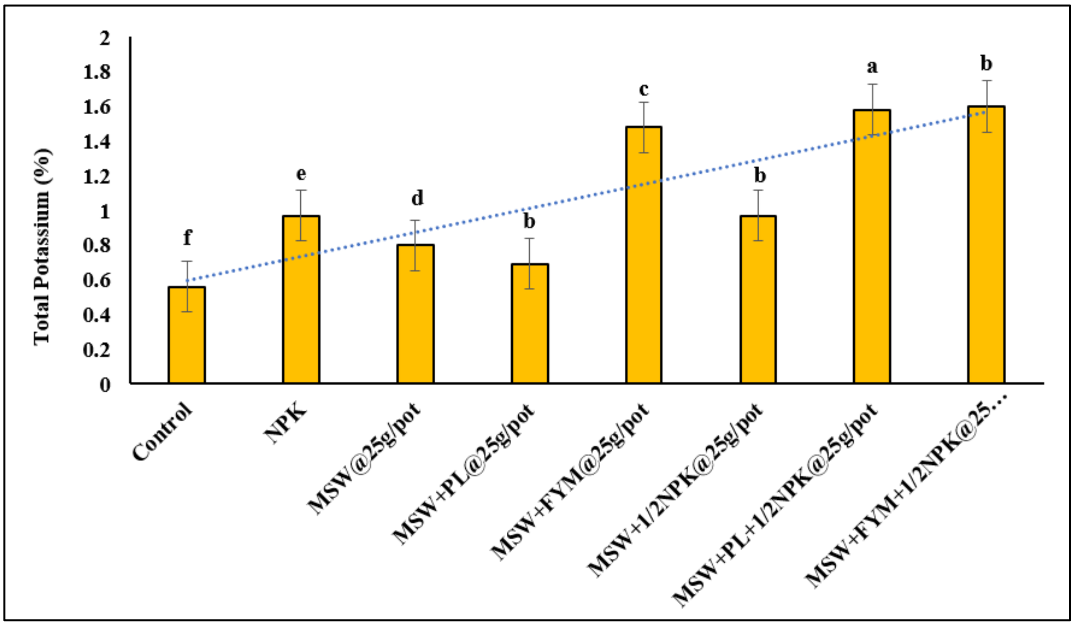

Figure 17:Effects of vermicompost on Total Potassium in maize

Iron Contents in maize

Among plant specimens, the iron content varies within a span of 29mg/kg to 52mg/kg in Figure 18. Among these variations, the highest iron content, reaching 52mg/kg, was documented in the treatment involving MSW+FYM+1/2NPK. Following closely, an iron content of 48.5mg/kg was observed in the MSW+PL+1/2NPK treatment, while the lowest measured iron content of 29mg/kg was attributed to the control.

Iron is necessary for plant growth due to its critical involvement in plant metabolism. Research indicates that fertilizers made from vermicompost contain more iron than those made from traditional compost. During vermicomposting, earthworms excrete significant amounts of iron and heavy metals back into the atmosphere using their calciferous glands (Soobhany, 2019). Composting depends on beneficial microorganisms. Merging these fertilizer sources can be especially advantageous when soil or plants need iron. Iron is essential for chlorophyll synthesis, which aids in plant photosynthesis (Yatoo *et al.*, 2022).

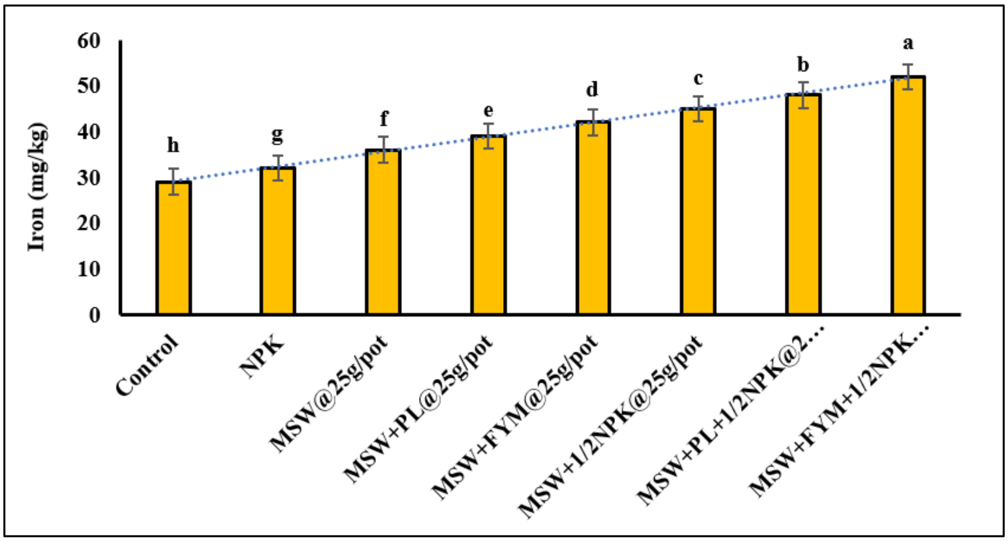

Figure 18: Effects of vermicompost on Iron Contents in maize

Zinc Contents in maize

In the realm of plants, the zinc content exhibits a range spanning from 32mg/kg to 58.3mg/kg in Figure 19. Among these variations, the highest zinc content, reaching 58.3mg/kg, was observed in the treatment involving MSW+FYM+1/2NPK@25g/pot. Following closely, a zinc content of 58.3mg/kg was recorded in the MSW+PL+1/2NPK@25g/pot treatment, while the lowest measured zinc content of 32mg/kg was attributed to the control.

Zinc is an essential nutrient that plants need in small quantities. It plays a role in internode elongation and hormone production. Furthermore, zinc is crucial for regulating gene expression. This might be linked to the mineralization effects of earthworms, which decompose organic matter into simpler forms that enhance microbial activity, releasing minerals. Zinc aids plants in synthesizing auxins, converting starch to sugars, and enhancing cold tolerance (Emendu *et al.*, 2021).

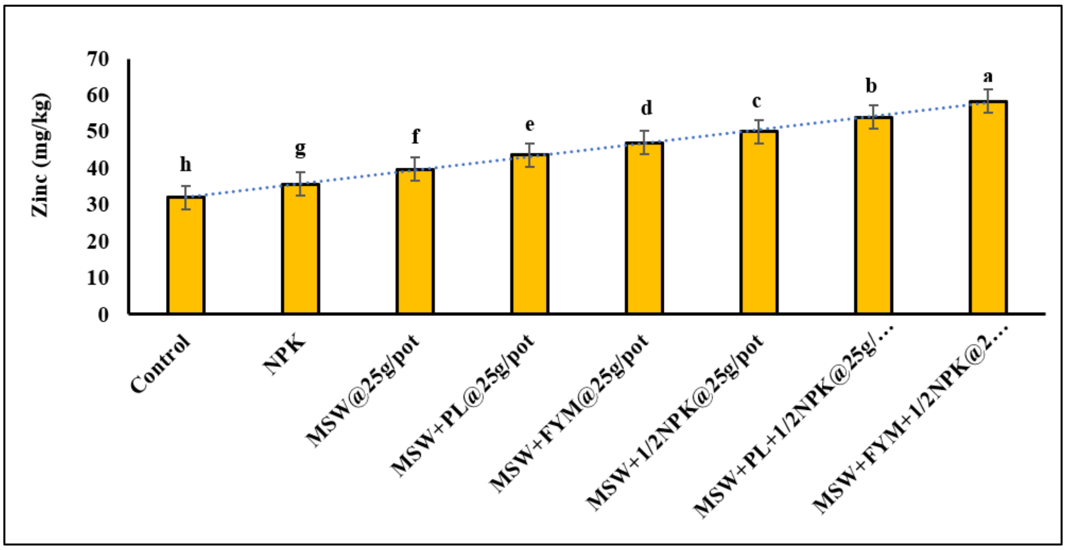

Figure 19: Effects of vermicompost on Zinc Contents in maize

Copper Contents in maize

Within the plant domain, the copper content spans a range extending from 14.4mg/kg to 31mg/kg in Figure 20. Among these variations, the highest recorded copper content of 31mg/kg was found in the MSW+FYM+1/2NPK@25g/pot treatment. Subsequently, a copper content of 28mg/kg was observed in the MSW+PL+1/2NPK@25g/pot treatment. On the opposite end of the spectrum, the lowest measured copper content of 14.4mg/kg was identified in the control. Both of these values were found to be statistically significant about each other and significantly different from all other treatment groups.

Copper is a crucial micronutrient that plants need in tiny quantities. It supports photosynthesis, and plant respiration, and activates various enzymes in plants. This aligns with the findings that vermicompost fertilizers contain a higher concentration of copper (Faazal *et al.*, 2023). The high copper levels may result from copper-based oxidizing enzymes present in the vermicompost. Additionally, copper is vital for the formation of plant cell walls (Daman *et al.*, 2016).

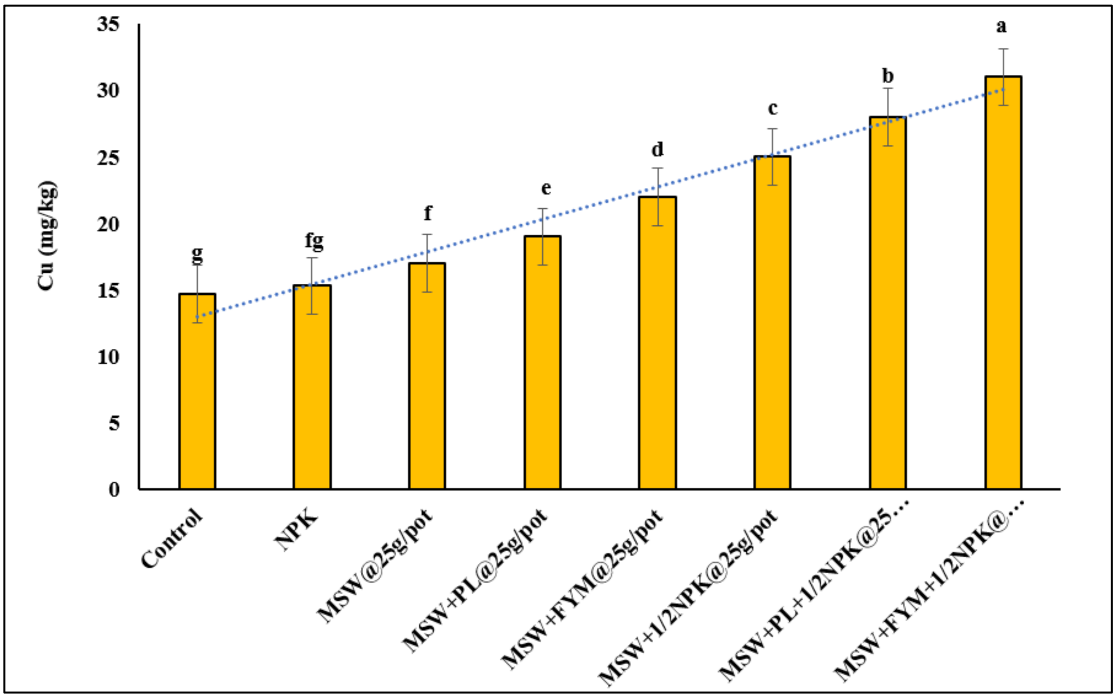

Figure 20: Effects of vermicompost on Copper Contents in maize

Manganese Contents in maize

Among plant specimens, the manganese content exhibits a span from 26.7mg/kg to 56.7mg/kg is illustrated in Figure 21. Within this spectrum, the highest manganese content of 31mg/kg was documented in the MSW+FYM+1/2NPK@25g/pot treatment. In succession, a manganese content of 50.5mg/kg was observed in the MSW+PL+1/2NPK@25g/pot treatment. On the lower side of the range, the minimum recorded manganese content of 26.7mg/kg was noted in the control. These two values exhibited a significant correlation with each other and were notably distinct from all other treatment groups.

Manganese is a crucial micronutrient for plants, needed in the second-largest amount after iron. It promotes photosynthesis, respiration, and the uptake of nitrogen by plants (Faazal *et al.*, 2023). In addition to supporting photosynthesis and the synthesis of chlorophyll, manganese functions as a catalyst for a number of enzymes. Additionally, manganese stabilizes nucleic acids, influencing the growth rate of plants (Daman *et al.*, 2016).

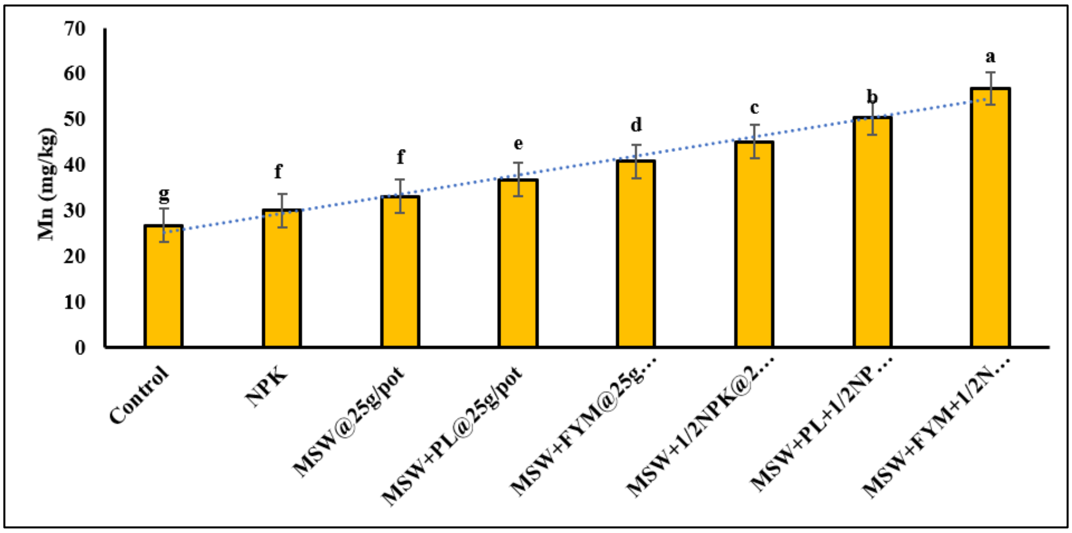

Figure 21:Effects of vermicompost on Manganese Contents in maize

EFFECT OF VERMICOMPOST APPLICATION ON SOIL FERTILITY AFTER HARVESTING OF MAIZE CROP

Soil pH

The examination of variance indicated the data quality for soil pH across various treatments in Figure 22. Soil pH values ranged from 7.34 to 7.83. Following the completion of the maize crop's growth cycle, soil pH was assessed. Notably, the highest recorded soil pH value of 7.83 was found in the control, followed by 7.64 in the NPK treatment. Conversely, the lowest soil pH value of 7.34 was attributed to the MSW+FYM+1/2NPK@25g/pot treatment.

The transformation of nitrogen (N) and phosphorus (P) into nitrates/nitrites and orthophosphates, alongside the conversion of organic molecules into intermediate organic acid species, are two potential reasons for the pH's notable shift from alkaline to neutral or acidic (Tejada and Benitez 2020).

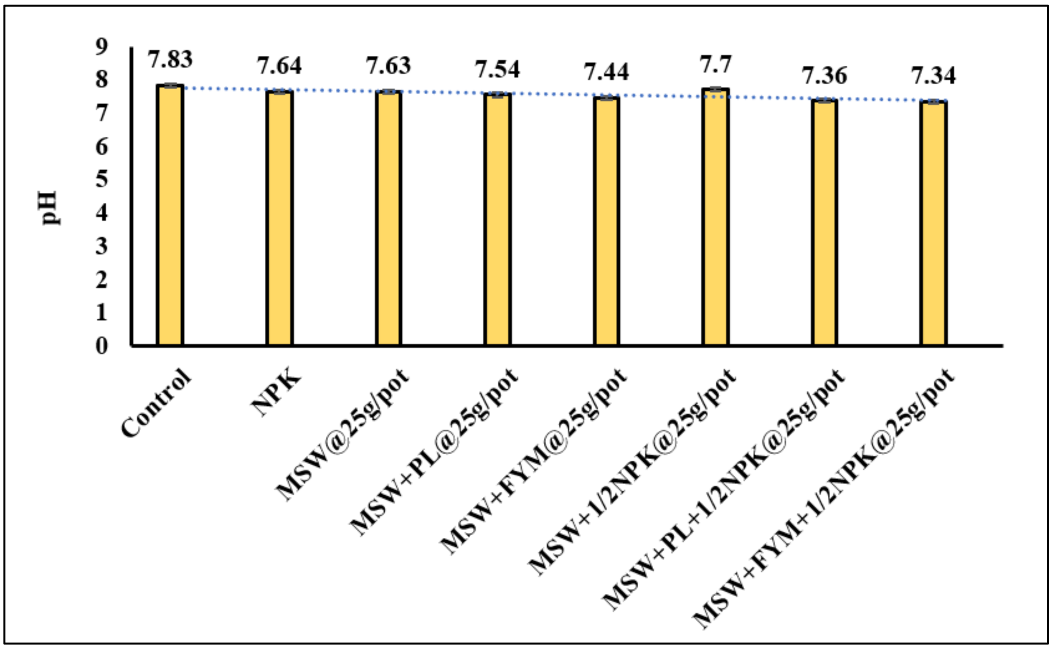

Figure 22: Effects of Vermicompost on Soil pH

Soil EC

The provided figure 23 illustrates the outcomes concerning soil electrical conductivity (EC) after the maize crop's harvest. After completing the maize crop growth cycle, an analysis of soil EC was performed. The results showed that soil EC ranged between 0.28 and 0.36 dS/m. The highest soil EC, recorded at 0.36 dS/m, was found in the control, while the same value was recorded in the MSW+FYM+1/2NPK@25g/pot treatment. In contrast, the lowest soil EC of 0.28 dS/m was evaluated in the control. Yuvaraj et al. (2019) indicated that the elevated levels of soluble salts caused by bacteria and worms contributed to the final vermicompost's increased EC values. This rise in EC signals waste mineralization (Ummer *et al.*,).

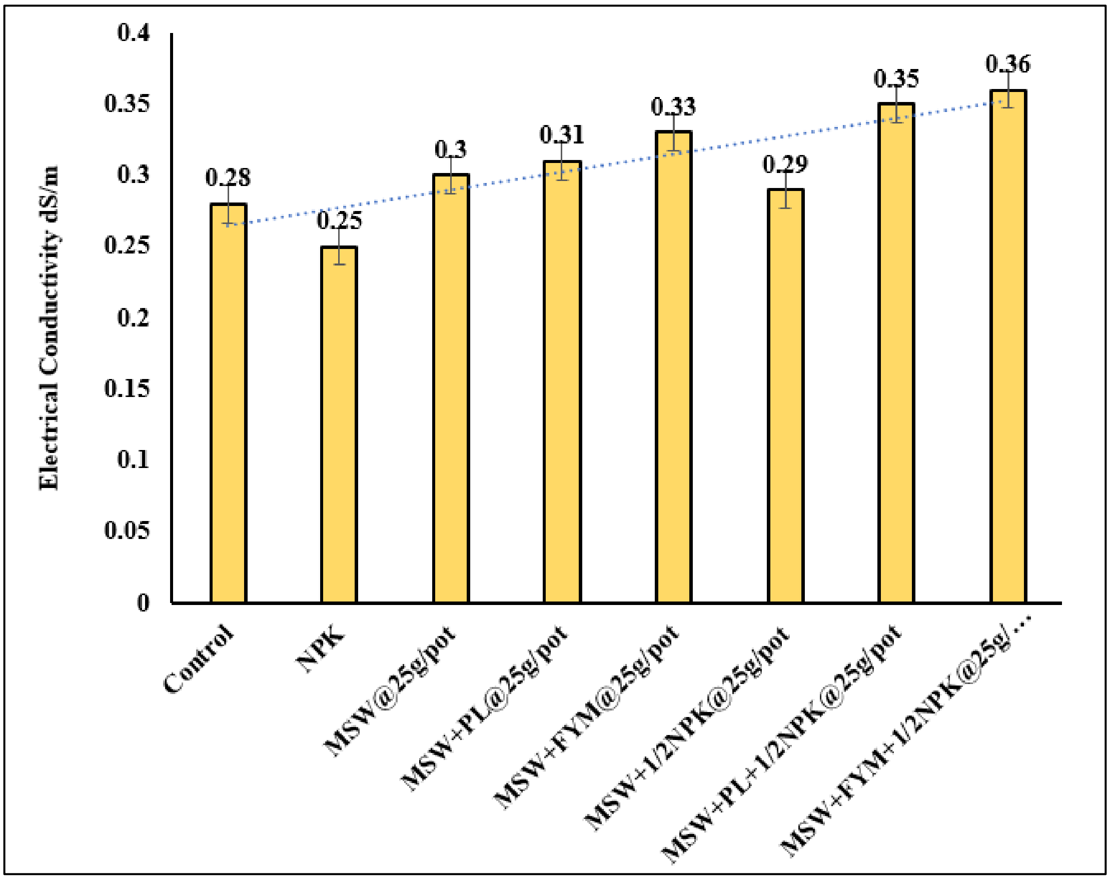

Figure 23: Effect of vermicompost on Soil Electrical Conductivity (dS/m)

Organic Matter in Soil

Figure 24 illustrates the organic matter (OM) content in the soil post-crop harvest. The organic content measured between 0.74% and 1.03%. The peak soil OM value of 1.03% was recorded in the treatment with MSW+FYM+1/2NPK@25g/pot, while the MSW+PL+1/2NPK@25g/pot treatment yielded a value of 0.95% treatment. In contrast, the lowest recorded soil OM value of 0.74% was found in the control.

Water-holding capacity (WHC), cation exchange capacity (CEC), and chelation ability are all improved by organic matter, which greatly improves soil quality. Researcher suggests that an increase in vermicompost correlates with higher levels of soil organic matter (Qasim *et al.*, 2023).But significantly higher with that of T_1 and T_2. Using organic fertilizers such as Vermicompost can effectively enhance the organic matter content in the soil as reported by Canatoy (2018).

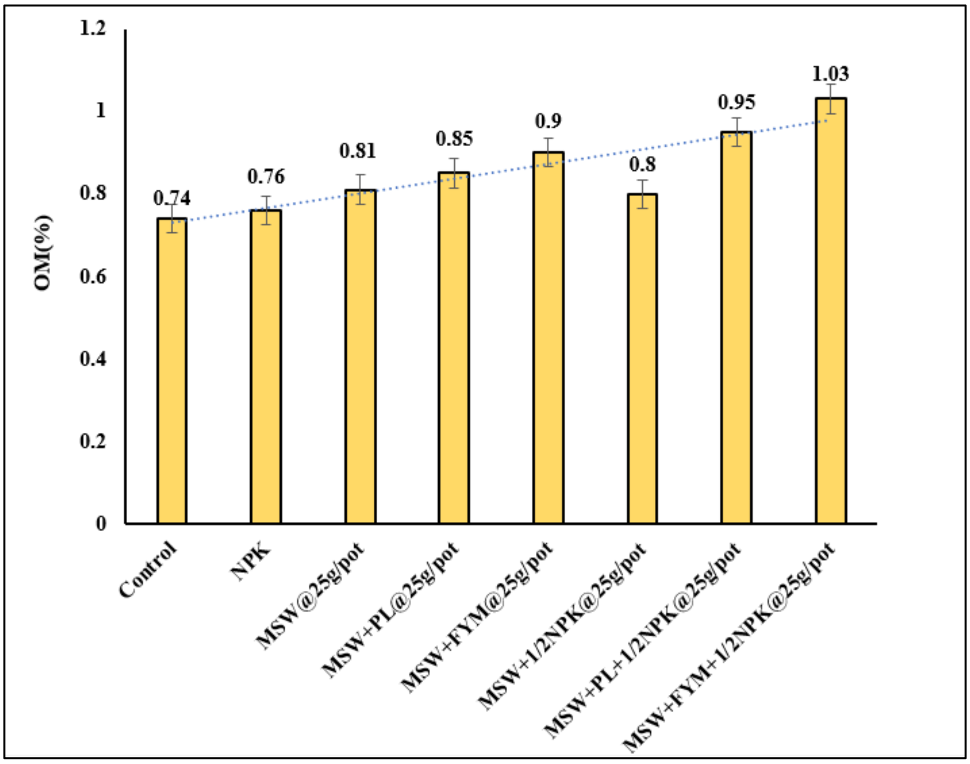

Figure 24: Effect of Vermicompost on Soil Organic Matter

Nitrate-Nitrogen Levels in Soil

The presented Figure 25 illustrates the outcomes concerning soil nitrogen (N) after the harvest of maize crops. The recorded soil NO_3-N levels encompassed a range from 17.6% to 34%. The highest soil NO3-N concentration of 33% was documented in the MSW+FYM+1/2NPK@25g/pot treatment, closely followed by a reading of 33% in the MSW+PL+1/2NPK@25g/pot treatment. On the contrary, the lowest soil NO_3-N content of 17.6% was observed in the control. The results revealed that the Nitrogen concentration improved from the pre-composting stage to the maturity stage. Earthworms contribute to active nitrogen mineralization, which raises vermicompost's nitrogen content (Mistry *et al.*, 2015). Early decomposition losses of N in the form of ammonia caused the nitrogen content to fall; this is dependent on the kind of material and its C:N ratio (Lim *et al.*, 2016a).

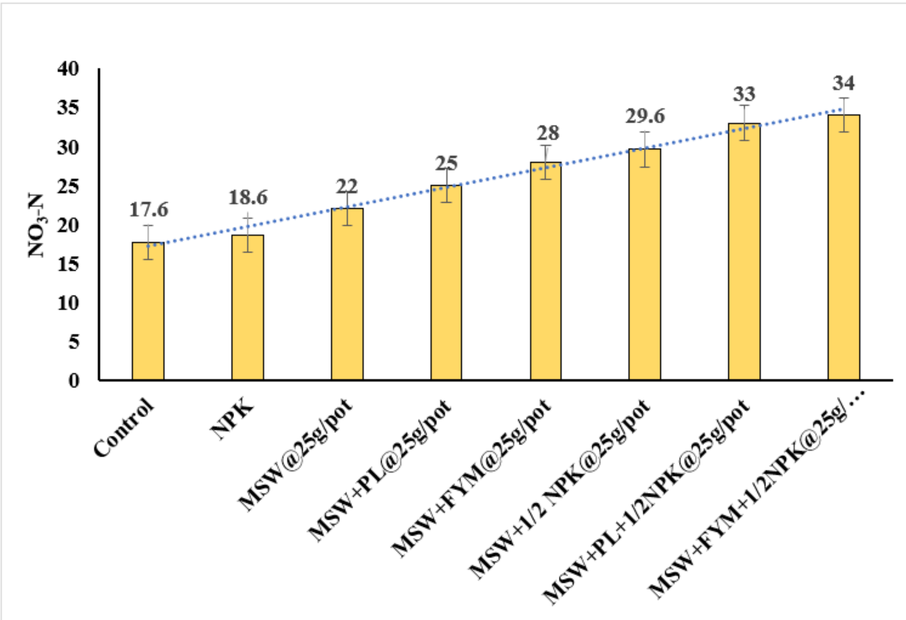

Figure 25: Effect of vermicompost on Soil Nitrate Nitrogen

Olsen Phosphorus Levels in Soil

The provided Figure 26 presents the findings concerning soil phosphorus (P) after the harvest of maize crops. The outcomes indicated that the highest average soil phosphorus value of 18.7% was registered in the MSW+FYM+1/2NPK@25g/pot treatment, followed closely by 18.3% in the MSW+PL+1/2NPK@25g/pot treatment. Conversely, the lowest average soil phosphorus concentration of 10% was noted in the control. The results also underscore significant distinctions among the various treatments (Ummer *et al.,*). The extractable phosphorus (P) levels, measured in mg/kg, showed no significant variation due to fertilizer treatments. Nevertheless, the highest concentration was recorded in plots treated with ½ RRIF combined with 2 tons of vermicompost per hectare (T_5) (Shaaibu and Rabiu, 2023).

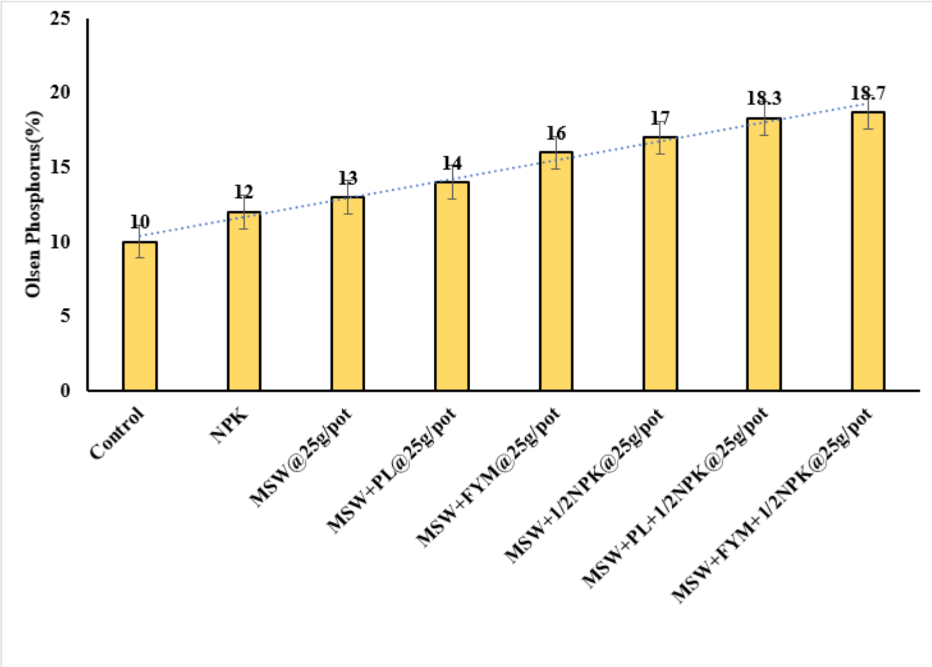

Figure 26: Effect of Vermicompost on Soil Olsen Phosphorus

Extractable Potassium Levels in Soil

The presented Figure 27 showcases the findings regarding soil potassium (K) after maize crop harvest. The outcomes indicated that the highest mean soil potassium value of 98.4% was documented in the MSW+FYM+1/2NPK@25g/pot treatment, closely followed by 92.6% in the MSW+PL+1/2NPK@25g/pot treatment. Conversely, the lowest mean soil potassium concentration of 33% was observed in the Control group. Earlier research findings and conclusions generally align with these results. Exchangeable K showed no significant changes due to the fertilizer treatments. The highest value occurred in plots treated with ½ RRIF plus 2 tons of Vermicompost per hectare (T_5) (Agegnehu *et al.*, 2015).

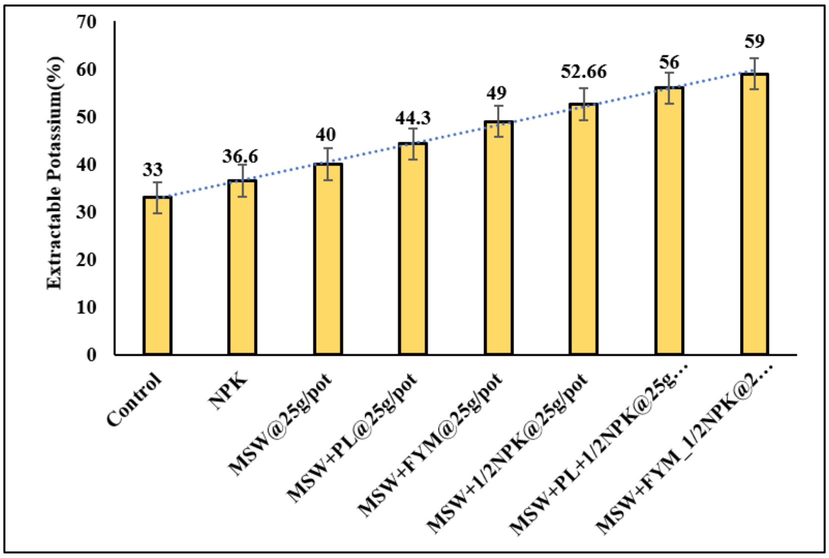

Figure 27 : Effects of Vermicompost on Soil Extractable Potassium

Iron Levels in Soil

Figure 28 depicts the iron content data within the soil. Enhanced bacterial activity contributed to a notably increased availability of iron. The highest average iron content of 4.5 mg/kg was noted in the MSW+FYM+1/2NPK@25g/pot treatment, closely trailed by 4.3 mg/kg in the MSW+PL+1/2NPK@25g/pot treatment. In contrast, the lowest average iron content of 3.4 mg/kg was observed in the control. Utilizing vermicompost fertilizer in cultivation offers significant advantages by enriching the soil with iron, facilitating chlorophyll production that enhances photosynthesis (Ummer *et al.*,). Additionally, it aids in electron transfer and nitrogen fixation within plants (Kebede *et al.*, 2023).

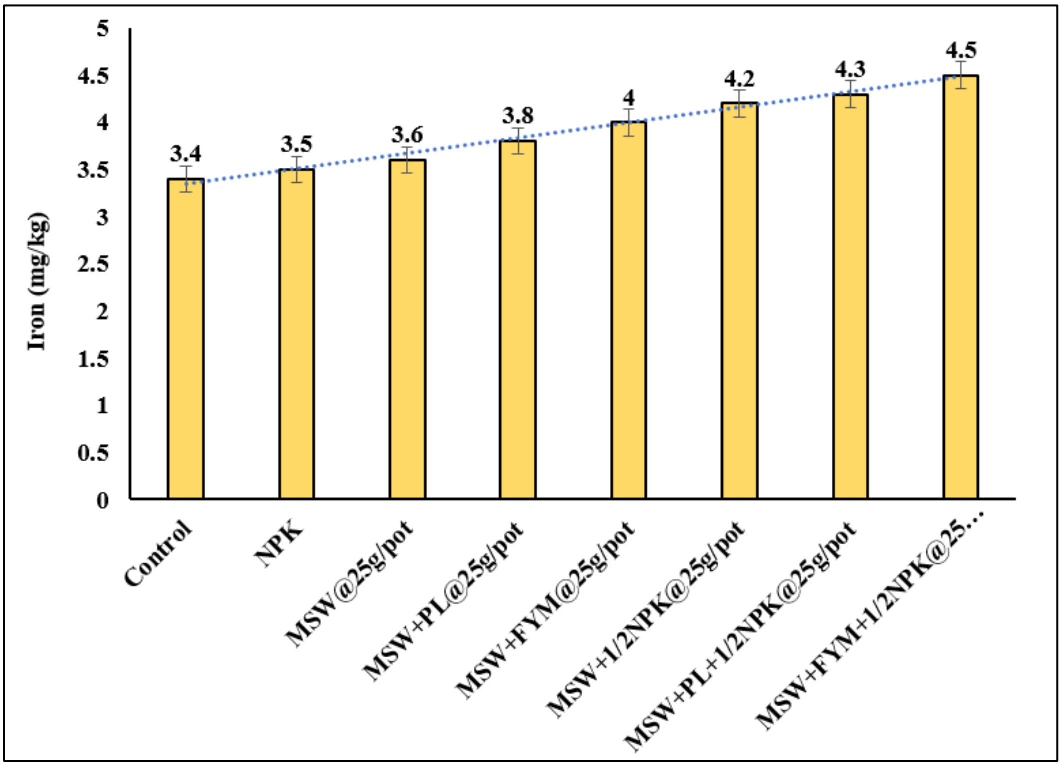

Figure 28 : Effects of Vermicompost on Soil Iron

Zin Levels in Soil

In Figure 29, based on the experimental results, the zinc concentration within the crushed maize material exhibited a range spanning from 1.18 mg/kg to 1.30 mg/kg. The maximum zinc level of 1.30 mg/kg was detected in the MSW+FYM+1/2NPK@25g/pot treatment, closely followed by 1.33 mg/kg. Conversely, the minimum recorded rate of 1.18 mg/kg was evaluated in the control. Zinc helps improve the quality of protein formation and is essential for maize growth. It is important for vital functions like photosynthesis and the intricate mechanisms involved in plant protein synthesis(Khan *et al.*, 2016).

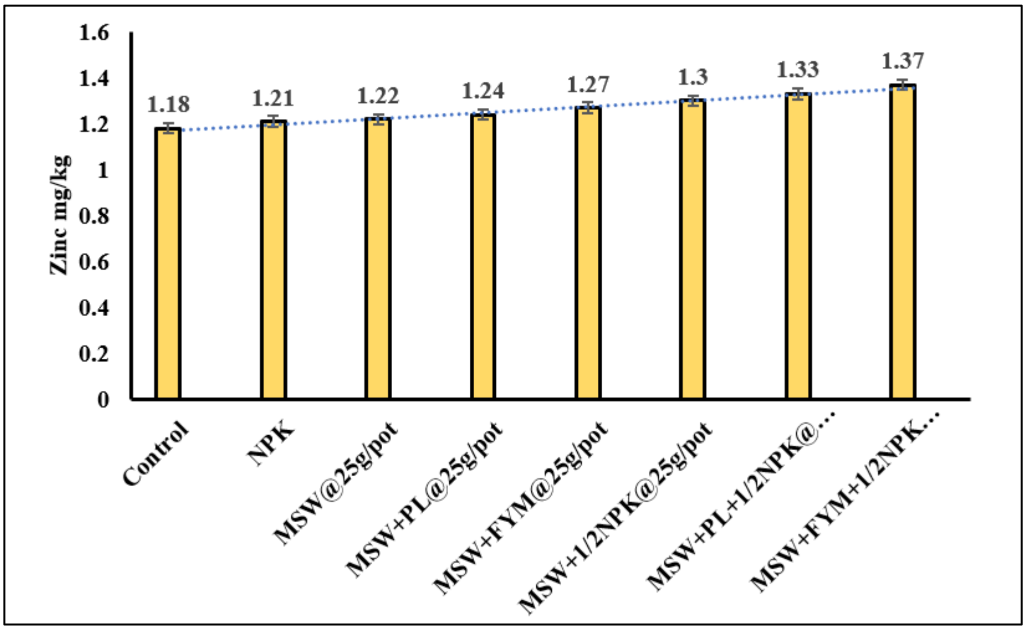

Figure 29: Effect of Vermicompost on Soil Zinc

Copper Levels in Soil

As illustrated in Figure 30, the experimental findings showed that the crushed maize sample's copper content ranged from 0.13 mg/kg to 0.38 mg/kg. The control group had the lowest average copper concentration of 0.13 mg/kg, while the MSW+FYM+1/2NPK@25g/pot treatment had the highest concentration of 0.38 mg/kg. Other metal ions cannot take the place of copper, which is necessary for the activation of numerous enzyme systems. Because it strengthens the stalk, stem, and branches, it encourages rapid growth. Enzymes that oxidize copper may be present in the organic materials utilized in the sample formulations (Ummer *et al.*,). Furthermore, copper directly aids in the formation of plant cell walls (Daman *et al.*, 2016).

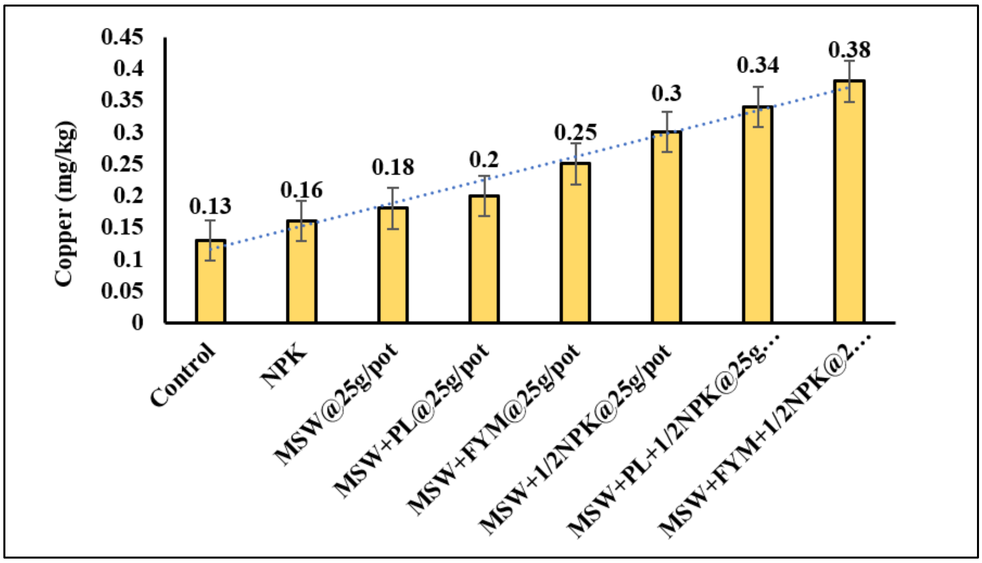

Figure 30: Effects of vermicompost on Soil Copper

Manganese Levels in Soil

According to the experiment's findings, manganese levels in crushed maize material ranged from 0.25 mg/kg to 1.94 mg/kg (Figure 31). While the control had the lowest mean manganese content of 0.25 mg/kg, the MSW+FYM+1/2NPK@25g/pot treatment had the greatest mean manganese content of 1.94 mg/kg. Manganese works as an enzyme activator that is involved in oxygen evolution in photosynthesis. Manganese is essential for the germination of pollen tubes, their development, the elongation of root cells, and disease resistance. This necessary component functions as an antioxidant cofactor for enzymes and helps a number of metabolic activities, especially photosynthesis (Senbayram *et al.*, 2015).

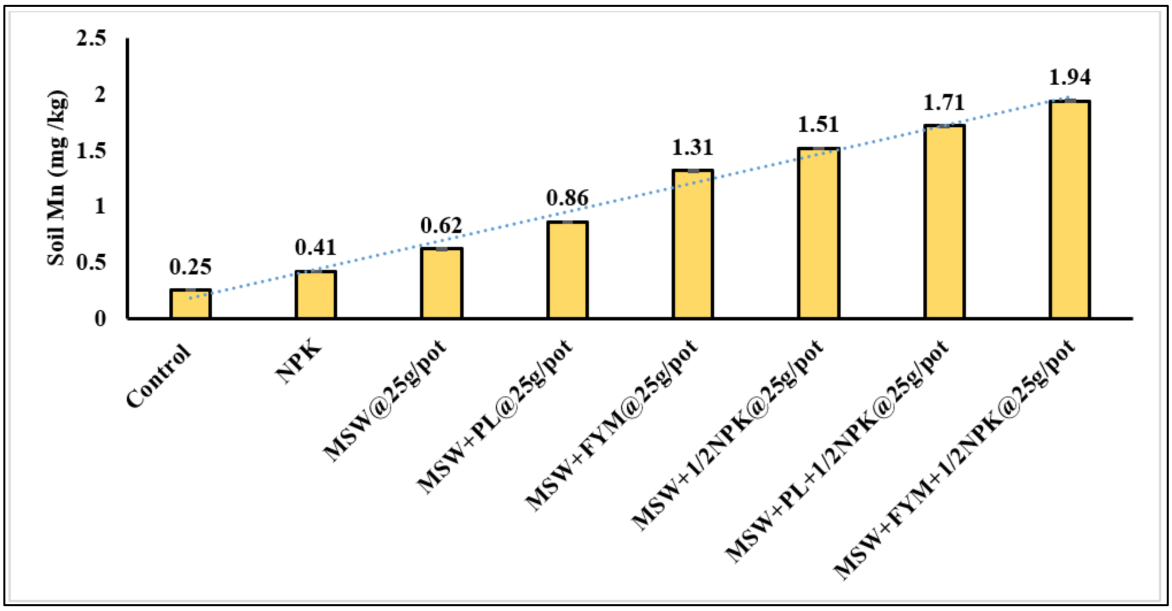

Figure 31: Effect of Vermicompost on Soil Manganese

CONCLUSIONS AND RECOMMENDATIONS

1. The study demonstrates that vermicomposting with a blend of Municipal Solid Waste and Poultry Litter (MSW+PL) yields high-quality compost characterized by ideal pH levels, increased nutrient concentrations (including NPK), as well as a boost in micronutrients (such as Fe, Zn, Cu, and Mn), thus proving it to be superior compared to other treatments. The decomposition of organic materials and the mineralization of nutrients depended on the activities of earthworms and microbes. It is recommended to utilize MSW+PL mixes for large-scale vermicomposting efforts to improve soil fertility and enhance crop yields. Additionally, regular monitoring of composting metrics and further investigation into long-term effects on soil are advised to optimize agricultural and environmental outcomes.
2. Vermicompost use significantly increased maize growth and nutrient levels, especially when combined with partial or complete NPK fertilization. Treatments combining MSW+FYM+1/2NPK and MSW+PL+1/2NPK consistently showed higher concentrations of NPK and essential micronutrients such as iron, zinc, copper, and manganese, as well as increased plant height and root and shoot weights. These results show that vermicompost and mineral fertilizers work together to improve nutrient absorption and soil quality. It is recommended to use vermicompost, especially MSW+FYM or MSW+PL, in conjunction with a balanced NPK fertilization treatment in maize farming to maximize growth, yield, and soil health.
3. By raising levels of organic matter, nitrate-nitrogen, phosphorus, potassium, and vital micronutrients (iron, zinc, copper, and manganese) after maize harvest, vermicompost utilization significantly improved soil fertility, particularly when combined with partial NPK fertilization (MSW+FYM+1/2NPK or MSW+PL+1/2NPK). These techniques also improved nutrient availability by increasing electrical conductivity (EC) and stabilizing soil pH. To improve crop yields, support sustainable farming methods, and strengthen soil health, vermicompost should be mixed with balanced inorganic fertilizers. The long-term effects on soil properties and production should also be further studied.

In conclusion, vermicompost is an efficient alternative to artificial fertilizers for growing fruits and vegetables since it is more environmentally friendly, cost-effective, and has no detrimental effects on human, plant, or aquatic health.

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