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Examining the Effect of Agrochemicals on Soil Microbiological Activity, Micronutrient Availability, and Uptake by Maize (*Zea mays* L) Plants

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Abstract: Introduction: Agricultural practices significantly influence soil microbial populations and physicochemical properties, which are crucial for crop growth and quality. This study aims to investigate the impact of different agrochemical applications on soil microbial dynamics, soil physicochemical properties, as well as yield and proximate properties of maize. **Methods:** Carefully gathered topsoil samples at depths ranging from 1 to 15 cm, were transported to Jimma University to cultivate maize. Over a period of up to 120 days, soil and maize samples were collected at specified days to analyze various parameters, including soil pH, microbial populations, as well as nutrient content both in soil and plants. The collected data was statistically analyzed using one-way ANOVA, with a significance level of $p < 0.05$. **Results:** The soil bacterial and fungal populations were measured on days 5, 10, 20, 40, 80, and 120. The highest total mesophilic bacterial count (TMBC) was measured in the pots containing compost (G) and the lowest in pots that received macronutrient fertilizers and glyphosates (B) (i.e. 91.8×10^5 and 13.13×10^5 cfu/g of soil, respectively). The highest total mesophilic fungal count (TMFC) was observed in pots containing glyphosates and compost (F) (i.e. 67.25×10^4 cfu/g soil) and again the lowest in pot treated with macronutrient fertilizers and glyphosate (B) (i.e. 3.23×10^4 cfu/g soil). Moreover, the pots treated with macronutrient fertilizers and glyphosate (B), macronutrient fertilizers (A), and micronutrient fertilizers (C) exhibited the lowest levels of Fe and Zn. Furthermore, the pots receiving macronutrient fertilizer combined with glyphosate (B), as well as those receiving macronutrient fertilizers (A) alone had the lowest concentrations of Mn and Cu micronutrients. Finally, in maize the lowest protein, fats, and carbohydrates (g/100g) were found in the pots treated with macronutrient fertilizer combined with glyphosate (B, 2.21 ± 0.2), micronutrient fertilizer (C, 8.57 ± 0.25), and glyphosates only (D, 57.34 ± 0.1). Maize treated with compost (G) showed the highest levels of Fe, Cu, and Zn, while macronutrient fertilizer combined with glyphosate (B) resulted in the lowest content of these micronutrients. Additionally, maize receiving micronutrient fertilizer (C) had the highest concentration of Mn, whereas those treated with glyphosates (D) had the lowest. **Conclusions:** Significant variations in soil's mesophilic bacterial and fungal populations, micronutrient levels, and nutritional composition were observed, indicating treatment-related changes. Generally, treatment with micromineral fertilizer combined with glyphosate (B) seemed to deplete the soil while compost treatment improved. Compost-treated soils exhibited the highest mesophilic bacterial and fungal count, as well as Fe and Zn micronutrient concentrations. The use of agrochemicals also had a negative effect on maize yield quality. The fluctuations in the soil parameters underscore the multifaceted effects of agrochemical treatments.

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Keywords: agricultural practices; crop quality; micronutrient concentrations; physicochemical properties; soil ecosystem; soil microbial populations

1. Introduction

Micronutrient deficiencies have emerged as a significant challenge to crop productivity in Ethiopia, with widespread deficiencies of Zinc (Zn), Iron (Fe), Manganese (Mn), and Copper (Cu) noted across various regions [1,2]. Practices such as increased cropping intensity, use of high-yielding varieties, and extensive fertilizer and pesticide application are expected to exacerbate these problems [1,3,4]. Inadequate food crop concentration and thus human intake of these elements can result in nutritional deficiency, anemia, compromised immune function, skin diseases, delayed child development, and intelligence-related issues [5–7]. This issue poses a growing threat to food and nutrition security in developing countries [8,9]

Furthermore, decreased pH [10] and use of pesticides can influence the availability of soil micronutrients (Cu, Fe, Mn, and Zn) and microbial populations [11,12]. In particular glyphosate, a commonly used herbicide, strongly binds to soil components, potentially affecting soil microbial communities and thus the general agro-ecosystem sustainability [13]. Despite certain prokaryotic and fungal species metabolizing glyphosate to protect susceptible species, the effectiveness of this mechanism in mitigating the herbicide's impact is still under scrutiny [14].

Several studies reveal that glyphosate concentrations exceed approved rates, possibly concealing the buffering effects of resistant members [13]. An overuse of glyphosate can affect soil microbial respiration and biomass [15]. Furthermore, long-term glyphosate use can lead to substantial changes in vegetation composition and growth by interfering with soil ecosystems and micronutrient availability [16].

The use of mineral fertilizers and pesticides, aiming to increase soil fertility and crop productivity, may also negatively impact the soil health and environment [17] by altering soil physicochemical properties, disrupting soil ecological balances, and disturbing the soil nutrient balance, decomposition rates, and nutrient bioavailability [18]. Furthermore, overuse of these chemicals can reduce the populations of beneficial soil microorganisms and enzyme activities that are essential for soil health and plant productivity [18]. Although mineral fertilizers alone may increase crop production, concerns exist regarding their environmental and long-term soil sustainability implications [19]. Mineral fertilizers can increase crop disease incidence and reduce soil micronutrient availability [20]

In addition, prolonged and uninterrupted cropping practices over several decades often result in modifications to soil properties, e.g. leading to a reduction in the levels of organic matter and essential micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) both as plant available species and bound to soil organic matter and other surfaces of the soil particles [21].

Ethiopia currently confronts numerous soil fertility challenges, including organic matter and micronutrient depletion due to factors such as topsoil erosion, acidity, and salinity [22]. Additionally, prolonged use of inorganic fertilizers and excessive pesticide application exacerbate these challenges [23]. The micronutrient deficiency in the soil system directly impacts plant uptake and, indirectly, human health [1,6]. Prolonged continuous cropping modifies soil physicochemical and biological characteristics and diminishes micronutrient availability, exacerbating soil fertility challenges in Ethiopia [22]. While widespread micronutrient deficiencies are evident in the western part of Ethiopia, data regarding the effects of agrochemicals on soil micronutrient availability and plant uptake are lacking [24]. This study aims to fill this gap by investigating the impacts of different agrochemical treatments on soil micronutrient availability, microbial dynamics, and maize proximate properties in western Ethiopia.

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2. Materials and Methods

2.1. The Intervention Approach of the Study

Initially, soil samples were gathered from three districts within the Kellem Wellega Zone: Sayo, Hawa Gelan, and Dale Wabara, all three from small-scale farmers' cultivated fields. Due to the environmental homogeneity at these three sites, the soil samples were combined. The pot experiment was conducted, implementing the intervention approaches of the study in the following manner (Figure 1).

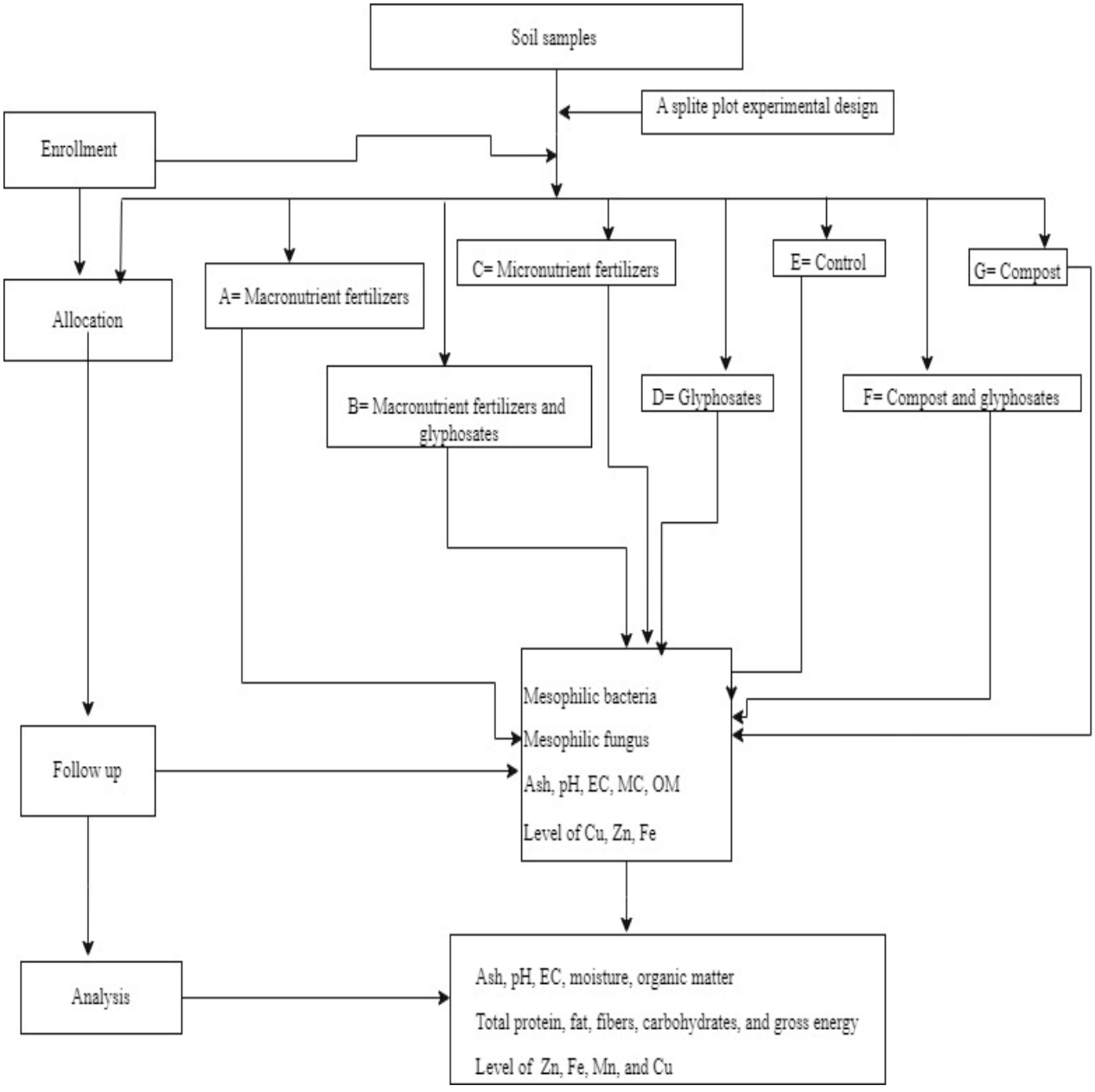

Figure 1. The intervention approach of the study.

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2.2. Study Setting

The pot experiment was carried out at Jimma University. However, the soil was collected from the Kellem Wellega zone, in the western part of Ethiopia's Oromia region, during June 2023. This zone lies approximately 672 km from Addis Ababa. Comprising 10 districts with a total population of 965,000 individuals, nearly half of whom are female [25]. Within this zone, there are approximately 175,000 households, each with an average size of 4.5 members [26].

For our study, we deliberately selected three specific districts: Sayo, Hawa Gelan, and Dale Wabara. These districts were chosen due to their adoption of high-yielding crop varieties, intensive cultivation methods, prolonged fertilizer use, soil acidification, and the absence of organic manure, management practices contributing to the observed micronutrient deficiencies.

The selected areas were positioned at an elevation ranging from 1701 to 1830 meters above sea level. The climate pattern is characterized by abundant summer rains, a brief wet season, and a dry winter. Annual precipitation varies from 800 to 1200 mm, while daily temperatures range between 15 and 25 degrees Celsius [27]. Renowned for its prolific agricultural output, the region produces a variety of crops, including coffee, maize, teff, wheat, barley, bean seed, and sorghum. The study area map is depicted in Figure 2.

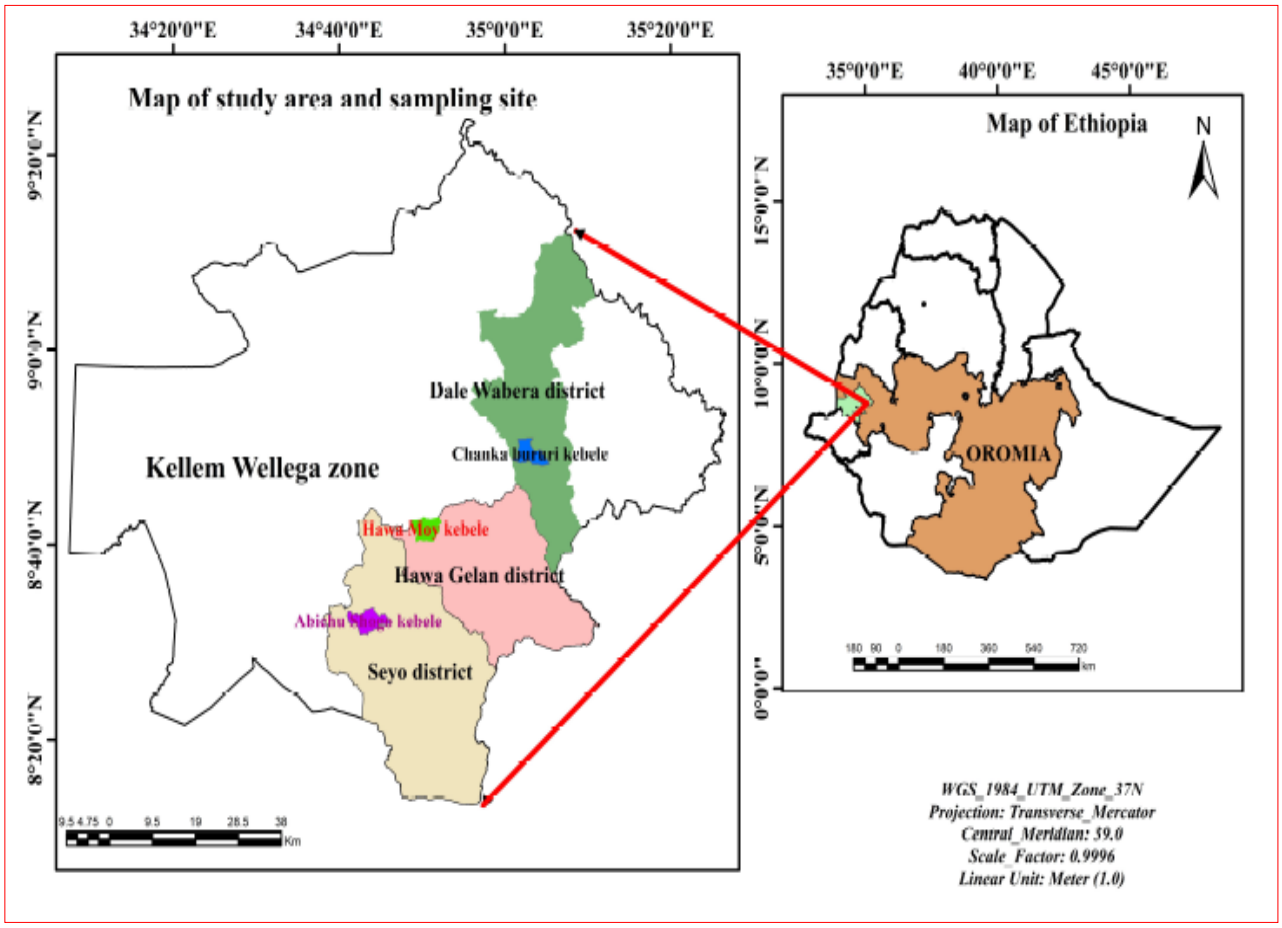

Figure 2. Geographical location of the study area for Sayo, Hawa Gelan, and Dale Wabara districts in Kellem Wellega zone, Western Ethiopia.

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2.3. Sample Collection from Farming Sites

Using a soil auger, topsoil samples were collected from the three selected districts of Kellem Wellega, i.e. Sayo, Hawa Gelan, and Dale Wabara, extracting topsoil from depths of 1 to 15cm. Before the collection process, surface debris and plant materials were carefully cleared by hand and stored in polyethylene bags for later disposal. The gathered samples were subsequently transported to Jimma University of Agricultural College, where they were mixed and utilized to cultivate maize within an open greenhouse environment.

2.4. Experimental Design and Treatment

The experiment employed a completely split-plot experimental design, each treatment consisting of three replications (n = 3) and labeled treatments A to G. Pots were arranged in an open greenhouse to ensure exposure to sunlight. The soils were collected from the farmers' fields during the period from September to November 2022. A survey has identified glyphosate as a prevalent herbicide in the local community [2]. Commonly used concentrations of active ingredients were combined in the plastic pots containing soil (10 cm deep) and homogenized. Plastic pots in seven treatment combinations including a control group, all in three replications were arranged in a split-plot experimental design. Maize, identified as a commonly consumed plant, was planted and allowed to germinate and grow until maturity, in which the temperature requirements can vary depending on the type of environment, and watered twice daily, in the morning and the evening.

The soil was sampled during the experiment. Parameters including Total Aerobic Mesophilic Bacteria Count (TMBC), total Mesophilic fungi count (TMFC), organic matter, moisture content, pH, electrical conductivity (EC), ash content, as well as iron, zinc, manganese, and copper levels were measured at intervals of 5, 10, 20, 40, 80, and 120 days.

Glyphosate quantities added were calculated based on soil density and volume. For glyphosate, 0.75 pounds or 0.34 kg of glyphosate is used per hectare, which translates to 2.67×10^{-6} kg or 2.61 mg of glyphosate per 16 kg of soil for each pot. The treatments included a control group that contains only the local soil or free of any treatments, as well as application of an herbicide, i.e. glyphosate, at a rate of 0.75 pounds per acre of soil, which is equivalent to 2.67 mg of glyphosate per 16 kg of soil. As per our experimental design, the soil was divided into seven equal-weight portions of 16 kg each, which were transferred into plastic pots given in Table 1.

Table 1. Designation of treatments and types of fertilizers utilized in the soil pot experiment.

Treatments	Added fertilizers
A	Macronutrient fertilizers
B	Macronutrient fertilizers and glyphosates
C	Micronutrient's fertilizers
D	Glyphosates
E	Control (free of any treatments)
F	Compost and glyphosates
G	Compost

Furthermore, the added amounts for all kinds of fertilizers are shown in Table 2.

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Table 2. Types, source, and rate of fertilizers required for the soil pot experiment.

Macro and micro fertilizers	Source	rate kg/ha	required for 16kg soil (each pot)
N	NH_4NO_3	120	0.96
P	P_2O_5	60	0.48
K	K_2O	50	0.4
Zn	$ZnSO_4.5H_2O$	60	0.48
Fe	$FeSO_4.7H_2O$	15	0.12
Cu	$CuSO_4.5H_2O$	2	0.02
Mn	$MnSO_4.H_2O$	360	2.88

2.5. Preparation of Compost Samples

For the compost, we selected nitrogen-rich (green) and carbon-rich (brown) materials such as banana peels, fruit scraps, leftover vegetables, sawdust, wood chips, and dried leaves [28]. We cut the green materials into smaller pieces using scissors or a shredder to accelerate the composting process. Breaking down the particles into smaller bits facilitates faster decomposition, enabling the soil to absorb nutrients more effectively. To prepare compost, a compost pit was established by digging a hole and combining green and brown materials. Nitrogen-rich materials were prioritized over carbon-rich materials to facilitate the organic matter decomposition process. Earthworms were introduced into the pit to enhance the speed of decomposition. Over time, earthworms and bacteria decomposed the organic components within the pit. To aid in the decomposition process, the contents of the pit were mixed every week. After six weeks, all the components were fully decomposed. The resulting compost was mixed into the soil in the pots just to be an alternative fertilizer to enhance plant growth. Referring to the literature, we mixed a 1 to 4 ratio of soil to compost for maize cultivation [29].

2.6. Moisture Content

The moisture content (MC) of the soil and plant samples was determined by weighing before and after oven-drying at 105°C for 24 hours. The soil and plant sales were cut into small pieces using a clean knife and placed in clean acid-washed porcelain crucibles. They were dried until a constant weight was achieved (24 h). The dried samples were stored in desiccators until subsequent weighing and analysis.

2.7. Ash and Organic Matter

Initially, we used 5.0 grams of ground powder soil samples and transferred them to labeled clean crucibles and then the soil sample at approximately 550°C in a muffle furnace until all organic matter was oxidized and then allowed to cool in the desiccator [30].

2.8. Determination of pH and Electrical Conductivity from Soil Samples

For the analysis, 15.0 grams of fresh (un-dried) and sieved soil, was carefully filled into two extraction cups. If the soil was adequately dry, a 2 mm sieve was used. Next, 30 mL of deionized water was added to each cup, and the mixture was thoroughly stirred to ensure proper mixing. The mixture was then allowed to stand for 30 minutes to equilibrate with atmospheric CO_2. Afterward, the mixture was stirred again, and the pH was measured using a pH meter [31].

To determine the electrical conductivity of soil samples, a 1:5 soil-to-water suspension was prepared by weighing 10 g of air-dry soil (< 2 mm) into a bottle and adding 50 mL of deionized water. The mixture was mechanically shaken at 15 rpm for 1 hour to dissolve soluble salts. For all samples, 15 ml of each sample was inserted with a digital multi-parameter (Bante 900- UK), and the results were recorded.

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2.9. Determination of Micronutrients from Soil Samples

At six specific sampling times soil samples were collected in the pot experiment. The initial sampling occurred 5 days after the application of pesticides, followed by subsequent samplings day no 10, 20, 40, and 80th day, and finally, the last sampling took place after 120 days. Subsequently, the samples were sectioned into small pieces using a sterile knife and transferred to clean, acid-washed porcelain crucibles. They then underwent oven-drying at 105°C for 24 hours. Once dried, the samples were finely ground into a powder using an acid-washed mortar and pestle until they passed through a 2.0 mm sieve. Following drying, the samples were ground into a fine powder using a commercial blender and stored in polyethylene bags within a desiccator until subsequent analysis. The concentrations of Zn, Fe, Mn, and Cu were determined using the acid digestion method [32].

Initially, 5.0 grams of ground powder soil samples were weighed and transferred to labeled clean crucibles. The dry ashing process was conducted in a muffle furnace with the temperature gradually increasing to 550°C and maintained for 6 hours. Subsequently, the ash was cooled and wet with water, followed by adding 2.5 ml of concentrated HNO_3. The crucible was covered with a watch glass and placed on a hot plate, with digestion performed at a temperature of 90 to 95°C for 1 hour. The ash was then dissolved in 5 ml of 9.25% HCl and digested again on the hot plate until the white fumes ceased and the sample was reduced to 2 ml. After cooling, 20 ml of distilled water was added, and the solution was filtered using a Whatman filter. The filtered sample was diluted up to the mark of a 50 ml standard volumetric flask and stored in a polyethylene container until analysis. All samples were prepared in triplicates with blanks prepared to assess background contamination from the reagents used. The Zn, Fe, Mn, and Cu content were then determined using an atomic absorption spectrophotometer (Shimadzu Model 6800 with graphite furnace Model GFA 7000).

2.10. Determination of Total Mesophilic Bacteria and Fungi Counts in Soil Samples

To ensure sterility, the polyethylene bags were subjected to a sterilization process for a minimum of 12 hours. Similarly, the glassware used in the experiment underwent treatment in a hot-air oven at a temperature of 160°C for 2 hours. The growth media and diluents, specifically distilled water, were autoclaved at a temperature of 121°C for 15 minutes. For microbiological analysis, soil samples were collected from each pot on days 5, 10, 20, 40, 80, and 120. The enumeration of colony-forming units (cfu) of bacteria and fungi was performed using the serial dilution and pour plate techniques [33] on asparagus mannitol agar [34] and rose Bengal agar [35], respectively.

The soil sample was mixed, and a suspension of 1g (dry weight equivalent) in 9 ml of sterile water was prepared. One milliliter of the soil suspension was then serially diluted (nine-fold) and used in the estimation of aerobic mesophilic bacterial and fungal populations via standard spread-plate dilution. Plates were swirled for homogenization, allowed to solidify, and then incubated at 28 ± 2°C for 18-24 hours for bacteria, and on potato dextrose agar containing 0.05% (w/v) chloramphenicol (to inhibit bacterial growth) for fungal isolation, and incubated at ambient temperature for 48-72 hours for fungi. After incubation, individual colonies were recorded as colony-forming units (cfu).

2.11. Quantification and Quality Analysis of Harvested Maize

2.11.1. Sample Preparation for Proximate Composition

Sample preparation converted the samples into homogeneous material for various quantity and quality analyses. Maize plant samples were dried and ground. Specific sample preparation was then conducted according to the sample type and analyses requested. Protein, fat, crude fiber, moisture, and ash were determined by the methods of [30].

2.11.2. Crude Protein Content

The Kjeldahl method was used to determine total proteins based on the procedure of [30] official reference methods were used. About 1g of each powdered maize sample was added to 0.2g of $CuSO_4$,

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and 1g of K_2SO_4 into a micro-Kjeldahl flask. Then 15 mL of concentrated H_2SO_4 was further added to each sample. Sample digestion was done at 420^0C for 75 min. The Kjeldahl digest tubes were washed with 50 mL of distilled water for two minutes then the micro-Kjeldahl flask was attached to the distillation unit. Then, 50 mL of 15 mol/L NaOH and hot boric acid (4%) solution having indicators of methyl red (10ml) and bromochresinol (7ml) were added in Kjeldahl the distillation unit released ammonia gases. Finally, borate anion (proportional to the amount of nitrogen) was titrated with standardized HCl (0.2N) in an automatic Kjeldahl analyzer (VELP SCIENTIFICA, UDK 159) method of determination was used to determine % protein content.

2.11.3. Crude Fat Contents

To initiate the extraction process, 1.5 to 2 grams of the sample are weighed and transferred into a clean extraction thimble previously rinsed with ether. The sample is then covered with defatted cotton, and the thimble with the sample is placed in a container and secured beneath the condenser of the fat extraction apparatus. The solvent beaker is dried in an oven at 105°C for 30 minutes, allowed to cool in desiccators to room temperature, and weighed. Subsequently, 30 to 40 ml of diethyl ether is added to the weighed solvent beaker, which is then placed under the condenser with a hand-tightened ring. The apparatus can be left unattended with occasional checks for approximately 1.30 hours until the extraction is complete. After the extraction period, the heater is lowered, allowing the thimble to drain completely [30].

2.11.4. Crude Fiber Contents

Weigh 0.6 grams of the oven-dried sample into a beaker, then add 15 ml of 1.25% sulfuric acid to the analyzer and boil for 30 minutes using a crude fiber digestion apparatus. At the end of the boiling period, remove the acid solution from the analyzer, rinse the residue three times with boiling distilled water, add 15 ml of NaOH, and boil for another 30 minutes. Repeat this procedure 3-5 times. Next, add 20 ml each of ethanol, diethyl ether, and acetone into the crucible containing the residue, and then remove the solvent mixture. Place the filter crucible with the residue in an oven and dry at 105°C for 2 hours. After drying, weigh the crucible and its contents and transfer them into a muffle furnace at approximately 550°C for 30 minutes. Using metal tongs, remove the crucible from the muffle furnace, allow it to cool, and weigh it again. Finally, calculate the percentage of crude fiber based on the weight changes observed throughout the process [30].

2.11.5. Total Carbohydrates and Energy Gross

Total carbohydrates were determined using proteins, fats; ash, fibers, and moisture proportions were added and subtracted from 100. (Total carbohydrate $= 100 -$ % of (Crude protei + Moisture + Ash + Crude fat + Crude Fiber). The gross energy value (expressed in kilocalories) was calculated using Atwater's conversion factors of 4 kcal/g for protein, 9 kcal/g for fat,4 kcal/g for carbohydrates, and 2 kcal/g for Fiber [36].

$$\text{Gross energy}\left(\frac{\text{kcal}}{100\text{g}}\right) = 9(\text{Crude fat}) + 4(\text{Crude protein}) + 4(\text{Total carbohydrate}) + 2(\text{Crude Fiber})$$

2.12. Statistical Analysis

Initially, the data were entered into EPI-INFO version 7 and subsequently imported into the Statistical Package for the Social Sciences version 26 (SPSS). Following this, descriptive statistics, encompassing mean, range, and standard deviations, were computed. Furthermore, the nutritional composition of agrochemical-treated maize was analyzed. Finally, a non-parametric test, specifically the Kruskal-Wallis's test of one way ANOVA, was used to compare the primary effects of the treatments.

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3. Results

3.1. Soil Physicochemical Properties

3.1.1. Soil Moisture (MC), ash (AC), and Organic Matter (OM) Content

When comparing the results across treatments labeled A to G (Table 1), notable variations emerge in the parameters measured. For soil moisture content, treatment of macronutrient fertilizers (A) consistently exhibits lower levels compared to other treatments, while treatments of micronutrient fertilizers(C), glyphosates (D), and control (E) generally display intermediate moisture levels. Conversely, treatment of compost and glyphosates (F) consistently resulted in the highest moisture content, particularly at longer time intervals (Table 3).

Regarding ash contents, the treatment of compost (G) consistently presents lower levels compared to other treatments. Treatment F tends to show relatively higher ash content, especially in extended durations (Table 3).

In terms of organic matter, the treatment of compost (G) consistently displays higher levels compared to other treatments, especially over longer periods, while the treatment of compost and glyphosates (F) shows relatively lower organic matter content, particularly in extended durations (Table 3). The non-parametric, one-way ANOVA analysis revealed notable variations in ash ($p = 0.01$) and organic matter ($p = 0.01$) contents.

Table 3. Moisture, ash, and organic matter of soil samples from pot experiments that were recorded at 5, 10, 20, 80, and 120th days of intervals.

sampling days	Parameters	Treatments						
		A	B	C	D	E	F	G
5	Moisture contents	25.6	27.6	24.4	26.2	25.8	35.4	28.6
	Ash contents	93.2	93.2	93	93.2	93	91.4	89.4
	Organic matter	6.8	6.8	7	6.8	7	8.6	10.6
10	Moisture contents	18.8	26	25.4	22	21.8	23.8	23.6
	Ash contents	89.2	87.6	91.2	91	91.2	91.2	85
	Organic matter	10.8	12.4	8.8	9	8.8	8.8	15
20	Moisture contents	23	24.6	24	24.4	24.4	28.2	27.6
	Ash contents	91.4	91.6	91.6	92	91.8	88.6	88.4
	Organic matter	8.6	8.4	8.4	8	8.2	11.4	11.6
40	Moisture contents	24.51	21.34	22.57	25.1	23.55	27.06	23.21
	Ash contents	91.74	91.7	91.88	92.16	92.02	89.02	89.48
	Organic matter	8.26	8.3	8.12	7.84	7.98	10.98	10.52
80	Moisture contents	24.8	22.9	22.38	23.06	22.42	23.38	21.43
	Ash contents	92.26	92.59	91.88	92.25	91.67	88.98	90.08

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	Organic matter	7.74	7.41	8.12	7.75	8.33	11.02	9.92
120	Moisture contents	17.69	23.1	20.2	24.97	15.22	18.81	16.75
	Ash contents	91.05	91.61	92.4	90.95	90.91	87.72	89.51
	Organic matter	8.95	8.39	7.6	9.05	9.09	12.28	10.49

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G).

3.1.2. Electrical Conductivity (EC) and pH

Comparing the results across different sampling days for treatments labeled A to G reveals significant variations. For pH levels, compost (G) treatment consistently gave higher pH values than other treatments across various sampling days (Table 4). In contrast, treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B), tend to exhibit lower pH levels, particularly at longer trial durations. Notably, treatments of micronutrient fertilizers (C) and glyphosates (D) display fluctuating pH levels, showing both higher and lower values throughout the trial period ($p = 0.00$) .

Regarding electrical conductivity (EC), the treatment of compost (G) consistently displays the highest values across most trial days, indicating greater conductivity compared to other treatments (Table 4). Treatments of micronutrient fertilizers (C) and glyphosates (D) also show relatively high EC values, especially at certain time points, while treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B) generally exhibit lower conductivity levels. The treatment of compost and glyphosates (F) stands out with significantly elevated EC values, particularly at later trial days, suggesting unique effects compared to other treatments ($p = 0.03$). (Table 4)

Table 4. Electrical conductivity (EC) and pH physicochemical properties of soil samples from pot experiments that were recorded at 5, 10, 20, 80, and 120th days of intervals.

Sampling days	**Parameters**	**Treatments**						
		A	B	C	D	E	F	G
5	pH	5.32	5.45	5.72	6.21	6.28	5.95	6.55
	EC	80.1	68.64	90.62	78.35	78.28	68.64	328.6
10	pH	5.58	5.63	5.4	6.2	6.04	6.5	6.51
	EC	68.08	80.37	117.6	70.55	95.8	139.8	164.1
20	pH	5.31	5.13	6.17	5.42	6.43	6.4	6.35
	EC	125.5	115	194.3	138.9	140.2	242.1	260.1
40	pH	5.47	5.04	6.42	6.23	5.84	6.39	6.42
	EC	83.52	78.44	89.95	86.3	93.15	152.2	152.2
80	pH	5.72	5.93	5.9	5.9	6.3	6.35	6.34
	EC	37	39.1	41.9	48.1	50.1	123.1	120.4
120	pH	5.82	5.5	5.89	6.26	5.96	6.36	6.45
	EC	91	69.7	55.9	47.9	36.2	120.4	79.7

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), Micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC), Electrical conductivity (EC).

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3.1.3. Total Mesophilic Bacterial Count (TMBC) and Fungus (TMFC)

Comparing the results across sampling days and treatments labeled A to G reveals intricate patterns in TMBC (Table 5). At day 5, treatment compost and glyphosates (F) demonstrate the highest counts for both TMBC and TMFC, with counts of $2.4x10^6$ and $7.x10^3$ colony forming units (cfu), respectively. Treatment of compost (G) also shows notably high TMBC counts (8x105cfu). However, control treatment € displays the lowest TMBC count ($2x10^5$) while treatment macronutrient fertilizers (A) record the lowest TMFC ($9.8 x10^4$cfu).

Table 5. Microbial count of soil samples from pot experiments that were recorded at 5, 10, 20, 80, and 120^{th} days of intervals.

Sampling days	Microbial Count	Treatment (cfu/g)						
		A	B	C	D	E	F	G
5	TMBC	$8x10^5$	$2.3x10^5$	$1x10^5$	$1x10^6$	$2x10^5$	$2.4 x10^6$	$8 x10^5$
	TMFC	$9.8 x10^4$	$3.8x10^4$	$3.5x10^4$	$1.07x10^5$	$1x10^3$	$7x10^3$	$5x10^3$
10	TMBC	$1x10^6$	$3x10^5$	$1.3x10^6$	$1.4 x10^6$	$2.5x10^6$	$4x10^5$	$5x10^5$
	TMFC	$1.02x10^5$	$5.2x10^4$	$9x10^3$	$1.32x10^5$	$3x10^3$	$2.9x10^4$	$2.1x10^4$
20	TMBC	$1.4x10^6$	$6.1x10^5$	$3.6x10^6$	$1.5x10^6$	$6.2x10^5$	$3.7x10^6$	$4x10^6$
	TMFC	$1.11 x10^5$	$4.2 x10^4$	$4.7x10^5$	$6.5x10^5$	$6.2x10^5$	$5.1x10^5$	$5.7x10^5$
40	TMBC	$5x10^6$	$6x10^6$	$6x10^6$	$5x10^6$	$7x10^6$	$7.5x10^6$	$9x10^6$
	TMFC	$5x10^4$	$4x10^4$	$5x10^4$	$7x10^4$	$2x10^4$	$8x10^4$	$7x10^4$
80	TMBC	$1.9 x10^6$	$7x10^5$	$9x10^5$	$6x10^5$	$4x10^5$	$1.1x10^6$	$1.5x10^6$
	TMFC	$4x10^4$	$2x10^4$	$3x10^3$	$2x10^3$	$1x10^3$	$6x10^3$	$4x10^3$
120	TMBC	$7x10^4$	$4x10^4$	$1x10^4$	$4x10^4$	$2x10^4$	$5x10^4$	$9x10^4$
	TMFC	$2x10^3$	$2x10^3$	$1x10^3$	$2x10^3$	$2x10^3$	$3 x10^3$	$5x10^3$

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Pesticides (D), Control (E), Compost and pesticides (F), Compost (G), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC).

By day 10, TMBC counts peak in the treatment of compost and glyphosates (F) at $2.5x10^6$, whereas the treatment of macronutrient fertilizers and glyphosates (B) exhibits the lowest count at $3x10^5$. For TMFC, treatment compost and glyphosates (F) again lead with a count of $2.9x10^4$, while treatment of micronutrient fertilizers (C) shows the lowest count at $9x10^3$cfu.

By day 20, treatment of compost G emerges with the highest TMBC count at $4 x10^6$, contrasting with treatment macronutrient fertilizers A's count of $1.4x10^6$cfu. Similarly, treatment of compost G leads in TMFC counts at $5.7x10^5$, while treatment of macronutrient fertilizers and glyphosates B presents the lowest count at $4.2x10^4$cfu.

By day 40, treatment of compost G maintains dominance with the highest TMBC count at $9x10^6$, contrasting sharply with treatment A's count of $5x10^6$ colony-forming units (cfu). For TMFC, all treatments exhibit relatively low counts compared to previous days.

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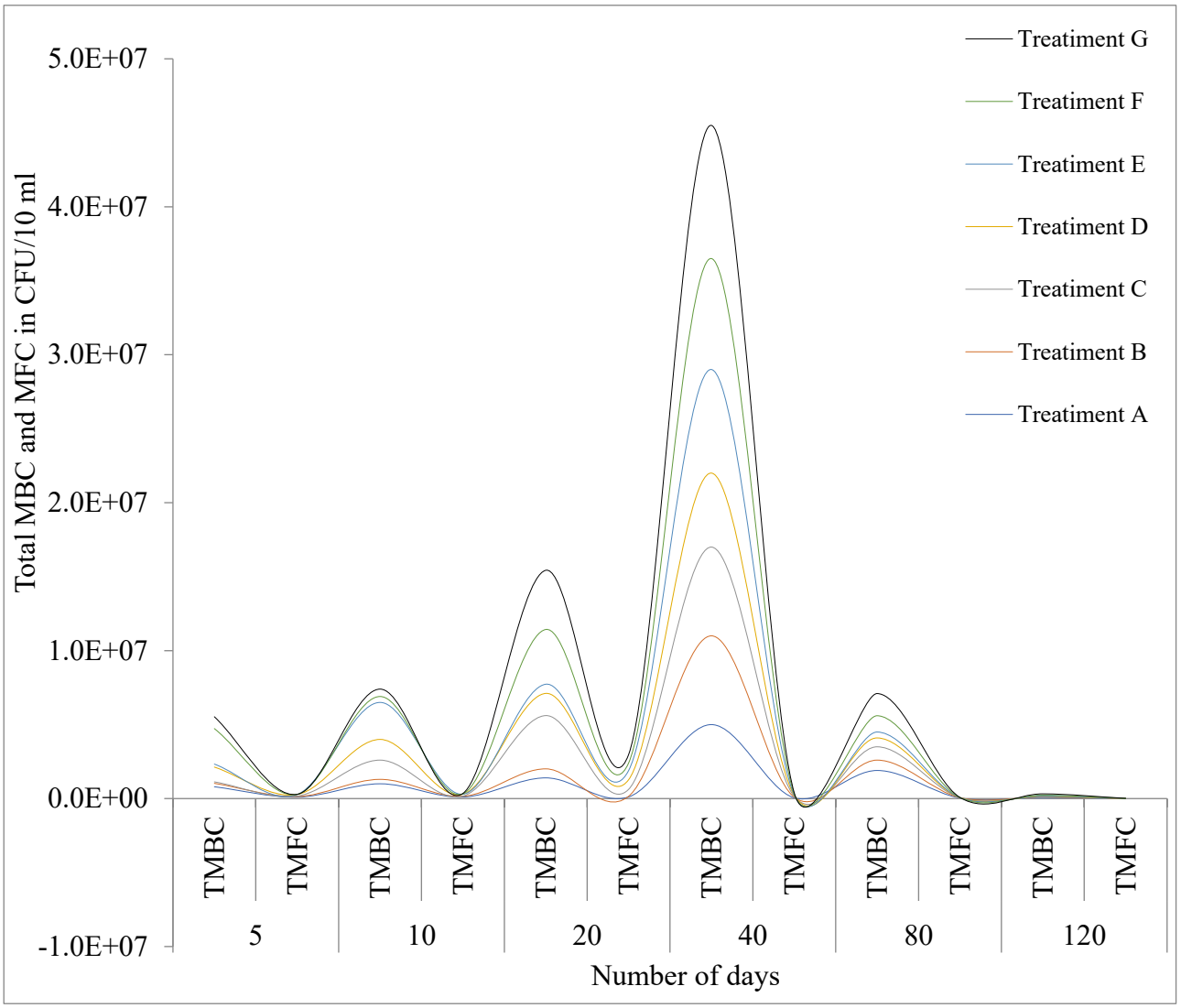
By day 80, TMBC counts decreased across all treatments, with treatment of compost G retaining the highest count at $1.5x10^6$, and treatment macronutrient fertilizers and glyphosates B showing the lowest count at $7x10^5$ cfu. TMFC counts also decline, with treatment of compost G leading at $6x10^3$ and treatment of micronutrient fertilizers C recording the lowest count at $3x10^3$cfu.

At day 120, TMBC counts decrease further, with Treatment of compost G maintaining the highest count at $5x10^4$ and treatment macronutrient fertilizers A recording the lowest count at $7x10^4$cfu ($p = 0.00$).

Similarly, TMFC counts diminish, with treatment of compost G leading at$5x10^3$and treatments of macronutrient fertilizers A, macronutrient fertilizers and glyphosates B, and control E displaying the lowest count at $2x10^3$cfu ($p = 0.03$)(Table 5).

In general, the graphical representation of total mesophilic bacteria count (TMBC), and total mesophilic fungus count (TMFC) (Figure 3) show that mesophilic bacterial found in pots initially increase up to 40 days after the startup of a growing season, followed by a significant decline until the harvesting period while mesophilic fungal population count tended to increase up to day 20 and then gradually decline (Figure 3).



Keys: Exponent(E), Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Pesticides (D), Control (E), Compost and pesticides (F), Compost (G), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC)

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Figure 3. A graphical representation illustrating the colony formation of total mesophilic bacteria count (TMBC) and mesophilic fungi (TMFC) in soil samples from pot experiments, recorded at intervals of 5, 10, 20, 80, and 120 days.

3.1.4. Soil Micronutrient Level Analysed from Pot Experiment

Comparing the results across trial days and treatments labeled A to G revealed variations in soil micronutrient concentration (Table 6). At day 5, the treatment of compost and glyphosates (F) stands out with notably higher values in Fe, Mn, and Zn, suggesting it's efficacy in promoting the accumulation of these elements. Conversely, treatment of macronutrient fertilizers and glyphosates (B) show to exhibit lower values, particularly noticeable in the Fe and Mn content.

By day 10, treatment of compost (G) displays elevated levels of Fe and Mn, while treatment of glyphosates (D) shows a significant increase in Zn content. In contrast, treatment of micronutrient fertilizers (C) demonstrates relatively lower values across most parameters.

Table 6. Fe, Mn, Cu, and Zn micronutrients of soil samples analyzed from pot experiments that were recorded at 5, 10, 20, 80, and 120th days of intervals.

Sampling days	Parameters	Treatments (PPM)						
		A	B	C	D	E	F	G
5	Fe	20.38	22.99	222.49	23.57	226.56	223.94	218.85
	Mn	60.95	65.69	210.67	64.22	244.62	208.76	238.18
	Cu	4.35	4.22	6.93	4.99	6.96	5.39	5.94
	Zn	2.18	2.81	23.41	2.4	25.58	30.81	29.8
10	Fe	29.72	30.71	258.37	27.66	289.37	253.53	305.84
	Mn	71.59	74.48	111.9	82.8	162.63	109.03	238.71
	Cu	4.12	3.36	2.89	1.1	1.75	3.26	4.02
	Zn	1.45	2.1	19.21	6.5	1.33	7.96	8.65
20	Fe	23.1	21.54	300.79	20.52	257.68	273.21	270.37
	Mn	121.48	204.4	127.91	88.38	114.01	222.73	170.17
	Cu	1.75	3.09	4.74	2.44	1.99	7.49	2.41
	Zn	4.84	16.75	1.12	1.06	5.79	20.86	22.75
40	Fe	27.22	28.13	308.89	30.51	305.89	349.26	292.95
	Mn	80.67	96.53	393.38	128.49	272.51	285.57	283.72
	Cu	3.06	5.18	7.25	7.04	5.81	7.9	2.3
	Zn	1.49	2.77	40.59	3.87	29.93	37.9	54.94
80	Fe	22.18	20.18	234.93	23.86	227.94	232.11	247.46
	Mn	103.34	82.67	288.48	121.83	220.87	223.59	260.21
	Cu	6.01	4.92	7.5	4.06	4.92	5.69	5.5
	Zn	1.53	1.74	24.67	1.11	24.36	24.12	23.63
120	Fe	23.74	21.96	235.36	22.98	226.27	232.87	233.06
	Mn	122.18	20.35	305.37	118.05	203.89	237.84	234.14
	Cu	4.79	3.71	7.06	5.05	3.61	6.04	4.79
	Zn	1.93	1.31	19.94	1.83	12.36	35.19	27.02
Overall mean	Fe	24.39	24.25	260.14	24.85	255.62	255.49	261.42
	Mn	93.37	90.69	239.62	100.63	203.09	214.59	237.52

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	Cu	4.01	4.08	6.06	4.11	4.17	5.97	4.16
	Zn	2.24	4.58	21.49	2.8	16.56	26.14	27.8

Key: Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G), iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn).

Moving to day 20, the treatment of compost (G) maintains its dominance with consistently high micronutrient values, especially evident for Fe and Mn. The control (E), however, presents lower values for Fe and Mn compared to the other treatments.

By day 40, treatment compost and glyphosates (F) continue to exhibit the highest values for Fe and Mn, while treatment of compost G surpasses others in Zn content. Notably, treatment of micronutrient fertilizers C consistently displays relatively lower values across all parameters.

As the trial progresses to day 80, the treatment of compost (G) maintains its lead with consistently high values for Fe, Mn, and Zn. Treatments of macronutrient fertilizers and glyphosates (B) and glyphosates (D) show varying patterns with fluctuations with time.

Finally, by day 120, the treatment of compost (G) remains prominent with notably high values of Fe, Mn, and Zn. Treatment micronutrient fertilizers (C) on the other hand, consistently demonstrates lower values..

Overall, compost treatment (G) consistently demonstrates higher values of Fe ($p = 0.00$*), and Zn ($p = 0.01$), indicating its potential efficacy in promoting the accumulation of these essential elements in the soil. Conversely, Treatment A, B, and D consistently display lower values across all parameters. The highest concentrations of Mn were found in the treatments of micronutrient fertilizers (C), while the lowest were observed in the treatments of macronutrient fertilizers (A), macronutrient fertilizers and glyphosates (B), and glyphosates (D) ($p = 0.00$)(Table 6).

3.2. Maize Yield Quality

Analyzing the results across different sampling days for treatments A to G reveals significant variations (Table 7). The lowest plant moisture contents (MC) and ash content (AC) were found in maize grown in the compost (G) treatment, with values of 12.63 ± 0.13 and 1.69 ± 0.1 in g/100g of samples, respectively. The highest significance of plant moisture contents ($p = 0.00$) was found in the macronutrient fertilizer treatment (A), and the highest plant ash content was observed for micronutrient fertilizer treatment (C) ($p = 0.00$) in g/100g of maize.

Table 7. Physicochemical characteristics and proximate composition of maize plants grown under fertilizer and chemical soil treatments in pot experiments.

Parameters	**A**	**B**	**C**	**D**	**E**	**F**	**G**
MC(g/100g)	14.41±0.15**	12.76±0.05	13.23±0.25	12.63±0.1	14.2±0.25	13.25±0.1	12.265±0.13*
AC(g/100g)	8.855±0.03	7.53±0.1	11.2±0.25**	8.62±0.1	8.14±0.25	8.51±0.05	1.685±0.1*
PC(g/100g)	9.48±0.25	11.29±0.8	8.569±0.25*	9.688±0.3	10.57±0.3	10.825±0.7	11.42±0.8**
TFC(g/100g)	2.675±0.1*	2.21±0.2*	3.21±0.1	3.977±0.01*	3.22±0.1	3.48±0.2	3.535±0.13

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CF(g/100g)	6.265±0.1 *	8.195±0. 03*	8.21±0.2	7.835±0.0 3	6.585±0. 13	6.64±0.1	6.855±0.0 3
CHO(g/100g)	58.915±0. 03	59.315±0 .2	66.23±0. 1**	57.34±0.1 *	58.41±0. 2	58.53±0. 15	65.49±0.2
Gross energy(kcal/100g)	308.375± 0.13*	313.265± 0.13	343.845± 0.03	320.16±0. 1	315.37± 0.05	317.23± 0.10	348.465±0 .08**
Fe(ppm)	48.165±0. 1	79.495±0 .03	78.545±0 .03	19.9875± 0.04*	54.905± 0.03	45.84±0. 05	81.4650.1 3**
Mn(ppm)	6.1±0.05	5.9575±0 .05	9.845±0. 03**	3.13±0.1*	4.375±0. 13	6.0125± 0.06	4.585±0.1 3
Cu(ppm)	1.17±0.2	0.775±0. 01*	1.425±0. 2	1.24±0.25	0.9675± 0.08	1.27±0.1 5	1.995±0.1 4**
Zn(ppm)	38.5±0.05	37.095±0 .08	48.375±0 .1	36.615±0. 08*	38.435± 0.1	37.8±0.0 5	50.855±0. 03**

Keys: Fertilizers(A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost(G), electrical conductivity (EC), moisture contents (MC), Organic matter (OM), total fats (TFA), Crude fibers (CF), iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Lowest (*) and Highest (**) treatment effect.

Regarding crude protein content ($p = 0.01$), in g/100g, the highest significant concentration was found in maize from the treatment of compost (G) (11.42 ± 0.8). For total crude fats (TCF), the highest level was seen in the glyphosate treatment (D) (3.98 ± 0.01). For total carbohydrates ($p = 0.00$) and crude fibers ($p= 0.00$) the highest contents were found in the micronutrient fertilize treatment(C), with values of 66.23 ± 0.1 and 8.21 ± 0.02 in g/100g of maize samples, respectively. Lastly, the highest total gross energy (kcal/100g) level was found in compost treatment (G) (348.465 ± 0.08) ($p = 0.00$).

The lowest concentration of crude protein (PC) was observed in treatment C (8.57 ± 0.25). For total crude fats (TCF), the lowest level was found in macronutrient fertilizer and glyphosate treatment B (2.21 ± 0.2), while the total carbohydrates (CHO) exhibited the lowest concentration in glyphosate treatment D (57.34 ± 0.1) in g/100gof maize samples. The lowest total gross energy (kcal/100g) and crude Fibers (CF) in g/100g were recorded for maize from macronutrient treatment A, with values of (308.375 ± 0.1) and (6.265 ± 0.1), respectively.

In terms of plant micronutrient concentrations, Fe ($p = 0.00$), Cu ($p = 0.03$), and Zn ($p = 0.00$) concentrations were the highest for compost treatment (G) and the lowest in the glyphosate treatment (D) and the treatments with macronutrient fertilizers and glyphosates (B). Finally, plant Mn ($p = 0.00$) concentration in ppm was the highest in micronutrient treatment (C) and lowest for glyphosate treatment (D) (Table 7).

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4. Discussion

This study highlights the significant impact of commonly used effort factors used in intensive agricultural management. The use of chemical fertilizer and glyphosate showed clear effects on soil biological and physicochemical properties, soil micronutrient concentration, as well as maize yield and quality. This experiment illustrates how excessive use of inorganic fertilizers diminishes the population of beneficial soil microorganisms by altering the functional diversity of the soil microbial community.

The total mesophilic bacterial count (TMBC) and total mesophilic fungal count (TMFC) exhibited significant differences among treatment groups. The compost-treated soil exhibited the highest TMBC and TMFC, suggesting the positive influence on soil bacterial populations. Compost is known to enrich soil microbial diversity and activity, providing organic substrates and favourable conditions for bacterial growth [37]. Additionally, the presence of glyphosates in compost-treated soil did not seem to hinder bacterial populations, actually indicating potential synergistic effects or tolerance to glyphosates [38]. Likewise, the introduction of inorganic fertilizers alters the structure of the soil microbial community, thereby impacting the composition and diversity of mesophilic bacteria, leading to periodic decreases in their population [39,40].

Furthermore, we observed a significant drop in mesophilic bacterial and fungal count in the pots treated with both macro and micronutrient fertilizers, as well as glyphosate, compared to untreated pots. This decrease may be attributed to the addition of glyphosate, a non-selective organophosphate herbicide that has been found to reduce phosphate enzyme activity [41]. The reduction of phosphate enzyme activity causes death of sensitive microorganisms [42]. Glyphosate, a common herbicide in agrochemical that disrupt soil microbial communities by inhibiting specific microbial pathways and reducing microbial biomass [43]. Conversely, compost amendments positively influenced bacterial populations, while chemical inputs had detrimental effects.

Furthermore, our study shows that glyphosate and inorganic fertilizer-treatment initially may increase mesophilic bacterial up to 40 days after the startup of a growing season, followed by a significant decline until the harvesting period while mesophilic fungal population count tended to increase up to day 20 and then gradually decline. The microbial counts may temporarily rise due to their ability to mineralize glyphosate and fertilizers for energy, but later on, these chemicals can selectively promote the growth of certain microbes while inhibiting others, leading to shifts in microbial diversity and overall abundance [44]. Additionally, inorganic fertilizers and glyphosate can be toxic to certain microorganisms and contribute to the decrease in microbial count in farming soil [45]. Moreover, the synergistic interactions between glyphosates, macro, and micronutrient fertilizers can further inhibit microbial soil community functions, ultimately leading to a decrease in microbial populations [46–48].

Compost-treated soil (G) exhibited the highest pH values, indicating alkaline conditions favorable for nutrient availability and microbial activity. The alkalinity of compost-amended soil may be attributed to the buffering capacity of organic matter, which helps maintain pH stability [49]. Additionally, the decomposition of organic materials releases alkaline substances, further contributing to elevated pH levels [50]. In contrast, treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B), tend to exhibit lower pH levels, particularly at longer trial durations. The acidifying effect of chemical fertilizers may stem from the presence of ammonium-based nitrogen sources, which undergo nitrification and release protons, lowering soil pH [51]. Moreover, acidic conditions can inhibit the growth and activity of beneficial soil microbes, disrupting soil biological processes [52]. Compost application promotes alkaline conditions conducive to nutrient availability and microbial activity, while chemical fertilizers may contribute to soil acidification and nutrient imbalances.

Electrical conductivity (EC) values exhibited significant variation among treatments, which reflects differences in soil salinity and nutrient concentrations. Compost-treated soil recorded the highest conductivity levels, indicating higher nutrient concentrations and organic matter content. The elevated EC in compost-amended soil may result from the decomposition of organic materials, which releases soluble ions and increases the electrical conductivity of soil solutions [53]. Additionally, the

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presence of organic matter enhances cation exchange capacity, facilitating the retention and release of nutrients, further contributing to elevated EC levels [54].

Conversely, treatments involving macronutrient fertilizers (A) and macronutrient fertilizers combined with glyphosate application (B) generally exhibited lower EC levels. This observation is consistent with the notion that chemical fertilizers may not contribute significantly to soil ion concentration compared to organic inputs like compost [55]. Additionally, glyphosate, a common herbicide used in conjunction with fertilizers, might further influence soil conductivity due to its impact on microbial activity and nutrient cycling [56]. This finding aligns with previous research suggesting that organic matter decomposition, as facilitated by compost application, can increase soil ion concentration and, consequently, electrical conductivity [55].

Similarly, soil organic matter content showed significant variation among treatments. Treatment of compost (G) consistently displays higher levels compared to other treatments, especially over longer periods, while treatment of micronutrient fertilizers (C) and glyphosates (D) show relatively lower organic matter content, particularly in extended durations, indicating limited organic inputs and microbial activity [57]. Compost amendments promote organic matter accumulation, stimulating microbial activity and enhancing soil productivity [46]. Conversely, treatment of micronutrient fertilizers and glyphosates shows relatively lower organic matter content, particularly in extended durations due to the chemical nature which may not contribute as significantly to organic matter accumulation as compost does [58,59].

Moreover, micronutrient levels (Fe, Zn, and Mn) displayed significant variation by the treatments. The application of compost enriches the soil with organic matter, which serves as a reservoir for micronutrients and promotes their release for plant uptake [60]. Additionally, compost enhances soil microbial activity, facilitating the mineralization of organic matter and the mobilization of micronutrients bound to soil particles [61]. Moreover, chemical fertilizers and glyphosate applications may also contribute to micronutrient deficiencies by disrupting soil microbial communities involved in nutrient cycling processes [62].

Furthermore, glyphosate, a broad-spectrum herbicide, can form complexes with micronutrients in the soil through chemical interactions, reducing their bioavailability for plant uptake. Glyphosate can also chelate with micronutrients like Fe and Mn, leading to deficiencies in plants [64]. Moreover, glyphosate usage alters microbial populations, impacting micronutrient uptake by plants, and inhibits soil microorganisms crucial for organic matter decomposition, thereby reducing mineralization essential for micronutrient availability [65].

Concerning the maize plant moisture and ash content the results support suggestions of maintaining a moisture level between 12 and 14% which is recommended for maize, as it ensures optimal conditions for storage [66]. The moisture content observed in this study was lower compared to some previous research [67] (9.76 - 10.6%), (68) (12.01%), and [69] (30-34%), but higher than that reported for Pakistan maize [70] (6.09 - 11.57%). This may be due to the compost treatment likely contributed to lower moisture content in maize due to improved soil structure and water retention capabilities [71]. Conversely, the macronutrient fertilizer treatment may have resulted in higher moisture content in maize due to the specific nutrient composition and application method of the fertilizer. Furthermore, macronutrient fertilizers typically contain nitrogen, phosphorus, and potassium, which can influence plant metabolism and water uptake, potentially leading to higher moisture levels in harvested grains [72]. This variability in moisture and ash content can be attributed to differences in soil water retention capacity and the water-holding capacity of organic amendments like compost [71], while the variation in ash content likely reflects differences in mineral content and soil fertility levels across treatments [73].

The ash content (lowest in the compost treatment) generally fell outside the range reported by several other studies, including [74](1.1-2.95%), [75] (3.76 - 4.39%), and [70](91.09 - 5.46%). The yield of ash content is often correlated with the presence of essential macro and micronutrients in food samples, as highlighted by [76] and thus has significant implications for human health and well-being [6,77]. Furthermore, the inorganic fertilizer treatment may have led to higher ash content in maize due to the specific micronutrients provided, such as iron, zinc, copper, and manganese that are

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essential for various physiological processes in plants, including enzyme activation and metabolism, which can affect the mineral composition of maize grains. Additionally, the compost may have facilitated nutrient uptake and utilization, leading to increased mineral content and thus higher ash content in maize grains.

Maize yield quality parameters such as crude protein, crude fat contents, crude fiber, total carbohydrate, and gross energy indicated significant differences among the treatments. In terms of crude protein content, the highest value was observed in maize flour from pots containing compost. These findings are in line with previous studies by [75] (9.24 - 11.58%), [68](4.58 - 7.24%), and [67](7.71 - 14.60). This suggests that compost amendments may enhance nitrogen availability and promote higher protein synthesis in maize plants [78] and genetic variability of maize seeds [79]. Furthermore, environmental factors, including soil type, climate, and agricultural practices can influence their nutritional composition [80].

Also crude fat content was the highest in maize in the compost treatment and then in line with results from other studies [67](2.17- 4.43%), (68) (3.84 - 4.61%) and [70] (2.87 - 12.54%). The observed differences in nutrient levels may be attributed to various factors, including genetic variability of maize and environmental factors such as soil moisture and temperature, which can influence the fiber content of maize grains [81].

Furthermore, the highest amount of crude fiber was found in maize from pots receiving inorganic micronutrient fertilizers and glyphosate, also in line with findings by [75] (64.02- 67.68), [68] (76.85- 80.31%), and greater than [67](69.66 - 74.55) and [82](82.40%). The variations in total fiber content (TF) may be associated with variances in soil organic matter content and microbial activity [83]. Carbohydrate and gross energy content varied significantly among treatment groups. Such variability could stem from differences in nutrient availability and soil microbial activity, ultimately affecting carbohydrate content and energy content of maize grains [84].

Moreover, iron, manganese, copper, and zinc content differed significantly among treatment groups. This variation may be attributed to differences in soil pH, and organic matter content [85,86]. Compost amendments positively impacted nutrient content and composition, emphasizing their importance in enhancing soil fertility and crop quality. Conversely, glyphosate treatment and micronutrient fertilizer treatment showed contrasting effects on nutrient availability and composition.

5. Conclusions

The study emphasizes the substantial impact of inorganic mineral fertilizer and agrochemicals on soil properties, maize yield and quality, including soil and plant micronutrient concentrations. Compost-treated soils exhibited the highest mesophilic bacterial and fungal count with higher Fe and Zn micronutrient concentrations. The glyphosate-treated soil showed the lowest micronutrient levels. Additionally, the presence of inorganic fertilizers and glyphosate resulted in a decrease in key soil parameters such as pH, electrical conductivity and organic matter. Maize from the agrochemical-treated pots generally displayed low crude protein, total fat, total carbohydrates, gross energy, and total fiber levels.

These findings suggest that soil fertility in the African western region, where small-scale farmers farm, may be compromised due to the extensive use of inorganic fertilizers and agrochemicals. To address this issue, it is recommended to implement sustainable agricultural practices that reduce reliance on agrochemical inputs, promote soil conservation measures, and adopt soil fertility enhancement techniques such as organic farming methods. Additionally, educating farmers on proper agrochemical usage through farmer education programs can help mitigate the adverse effects on soil health and crop productivity in the long term.

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