Response of Soil Microbial Community (Bacteria and Fungi) to Organic and Inorganic Amendments Using Tomato as a Test Crop

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ABSTRACT: A field experiment was conducted to evaluate the response of soil microorganisms (bacteria and fungi), to some soil amendments (organic and inorganic) at site A and site B. The experiments were laid out in a randomized complete block design (RCBD). The treatments applied were compost (3.4 t/ha), poultry manure (4.2 t/ha), *Tithonia diversifolia* (4.8 t/ha), NPK (15:15:15) (0.8 t/ha) at 120 kg N/ha, and the control. Treatments were replicated three times. Tomato seedlings were raised in the nursery and transplanted to the field after 3 weeks with a spacing of 50 × 50 cm. Soil microbiomes (Fungi and Bacteria) were isolated using the serial dilution technique. Compost improved both the total number of fungi by 12%–178% and diversity by 1.09%–85% compared to the other amendments at both sites, while the diversity of bacteria was increased more by *Tithonia diversifolia* (11%–75%). The total number of bacteria was highest in plots amended with compost at site A. Compost had the highest percentage of bacteria suppressed compared to other amendments studied at both sites (27.3% and 28.5%, respectively). NPK had the highest bacteria suppression at site A. The plot amended with NPK had the highest percentage of bacteria enhanced at site A. NPK had the highest at site B. Poultry had the highest reduction in bacteria at site A. *Tithonia diversifolia* had the highest percentage proliferation of allochthonous bacteria at both sites with 23.7% and 27.7%, respectively, while compost plots had the least allochthonous bacteria at both sites. At both sites, the percentage of suppressed fungi was highest in plots amended with poultry manure and control. Compost and *T. diversifolia* had the highest percentage of fungus growth reduction in site A (26.3%). At site A, compost had the highest percentage of allochthonous fungi (29%). Application of compost, poultry manure, and *Tithonia diversifolia* is recommended for the improvement of soil microbial properties.

KEYWORDS: Tomato, soil fungi, soil bacteria, organic amendment, allochtonous, soil microbial properties

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Introduction

Tomato is one of the most popular and important vegetable and edible fruit crops widely grown in the world. Tomatoes play a vital role in the human diet and are a good source of vitamins and minerals. The fruits can be eaten raw, cooked, or processed into juice, sauce, ketchup, puree, paste, or powder (Olaniyi & Ajibola, 2008). According to data from Faostat, the world produced 186.821 million metric tonnes of tomatoes on 5,051,983 hectares in 2020, achieving an average yield of 37.1 metric tonnes per hectare (mT/ha 1) (Branthôme, 2022). However, in Nigeria, production per hectare was 4.4 mT/ha, which was very much below the world average yield (Branthôme, 2022). One of the probable reasons for this poor yield is the poor fertility status of the soil. A major problem facing crop production in the Southern Guinea Savanna ecological zone of Nigeria is the low fertility status of the soil (O. Fawole & Olowonihi, 2008). This therefore necessitates the use of large amounts of inorganic fertilizer for maximum plant growth and yield (O. B. Fawole & Alori, 2017).

Over the years, the idea of practising intensive agriculture has been to achieve high productivity; however, this practise has adversely affected soil health and biodiversity despite the remarkable increases in overall food production (Tuğrul, 2019). Long-term usage of inorganic fertilizers causes soil, water, and environmental pollution, food insecurity, the development of pathogen/pest resistance, residual toxicity towards micro and macro organisms, and a loss of biodiversity (Ruano-Rosa & Mercado-Blanco, 2015). This therefore necessitated the need for environmentally and human health friendly, sustainable, and alternative farming practises.

Organic farming is a sustainable and affordable system that strictly prohibits the use of synthetic fertilizers, thereby reducing the negative effects of chemical fertilization (Ye et al., 2020). It is one of the oldest ways of practising sustainability in agriculture (Faissal et al., 2017). Application of organic amendments such as compost, plant debris, animal manure, peat moss, and organic mulch increases the organic matter content of the soil. It is also a major substrate in the management of soil and plant health as well as the suppression of diseases caused by soil-borne pathogens. The organic matter content of soil is used to determine soil health as it governs the physical, chemical, and biological properties of soil (Gómez-Sagasti et al., 2018). It has been reported that the presence of soil organic matter can reduce bulk density and increase water holding capacity and soil aggregate stability (Gómez-Sagasti et al., 2018). Organic matter supplies micro-organisms with essential nutrients (Reeve et al., 2016), which increases the microbial population, catalyses their activity (Larkin, 2015), and allows for high biodiversity (Turmel et al., 2015). As stated by Chandrashekara and Bhatt (2014) and Scotti et al. (2015), organic matter aids in natural disease suppression and soil fertility, thereby improving soil health.

Compost, as a type of organic amendment, has been known to improve the growth and yield of plants by improving the physical and chemical properties of the soil, enhancing nutrient availability (Chaney & Ramsubhag, 2015). Soil can be enriched through the incorporation of green manures (Larkin, 2013), which are an important alternative source of organic fertilizers (Hafifah et al., 2016). Green manure has a lot of benefits for the soil, which range from soil organic carbon enhancement, soil health improvement, high agronomic productivity (Hafifah et al., 2016), soil microbial biomass enhancement, and activity enhancement (Larkin, 2013). *Tithonia diversifolia* from the Asteraceae family, used as green manure due to its high nutritional composition, has proven effective in improving soil fertility (Hafifah et al., 2016), the physical properties of soil (Dayo-Olagbende et al., 2020; Hafifah et al., 2016), and crop yield (Babajide et al., 2012).

The role of microorganisms is vital in the ecosystem; however, the method of intensive agriculture does not support their healthy population, which could result in low productivity (Christopher, 2017). Soil microorganisms are involved in many biogeochemical processes in the soil. Soil microbes are important to life as they play a pivotal role in nutrient cycling and are responsible for the biological fertility of the soil (Christopher, 2017). They are great determinants for soil performance through the decomposition of plant materials and residues to increase the organic matter content of soil, thereby improving the soil's quality (Faissal et al., 2017). There has been well documented information on how organic amendments improve soil fertility and productivity. More importantly, research results show that the use of synthetic chemicals (fertilizers, pesticides, and herbicides) results in toxic residues in food, enhances environmental pollution, and eliminates non-target organisms from the ecosystem. There is a need to study the response of soil microorganisms to some soil organic amendments since soil microorganisms are important energy transformers and nutrient regulators in agro-ecosystems.

This research therefore aimed at assessing the response of the soil microbial community (bacteria and fungi) to some organic and inorganic soil amendments in an alfisol (the mapping units had accumulation of clay in the B- horizon (argillic B-horizon) and base saturation by NH_4OAc at pH 7.0 > 50% (Adegbite et al., 2020; Adekiya et al., 2022)) soils cropped with tomatoes. This will confirm the sustainability of the use of the studied organic materials in agriculture as biofertilizer, noting the significant roles soil microorganisms play in nutrient cycling and availability. The effect of inorganic fertilizer and three organic amendments on some soil physical and chemical properties and the effect of inorganic fertilizer and three organic amendments on tomato growth and yield were also assessed.

Materials and Methods

Experimental Site: The experiment was conducted at the Teaching and Research Farm and the staff quarters of Landmark University, Omu-Aran, Kwara State, Nigeria. The farm is located in the derived savanna ecological zone of Nigeria (Latitude 08° 9′ N and Longitude 05° 61′ E. The coordinates for the staff quarters are Latitude 08° 12107′ N and Longitude 05° 08915′ E). These were taking using a handy GPS. The area's annual rainfall ranges from 600 to 1,500 mm (Adekiya et al., 2022). The soil is formed on an undifferentiated basement complex. It is well drained and dry. Presence of few medium- sized pebbles and quartz stones on the surface. No evidence of salt and alkali present (Adegbite et al., 2020; Adekiya et al., 2022).

Figure 1 shows a profile pit at the study area. The chemical characteristics of the soil are as indicated in Table 1.

Experimental layout and design: The study adopted a two-by-five factorial design. Two sites (site A, sandy loam, and site B, sandy soil) and five soil amendments (compost, animal manure, *Tithonia diversifolia*, inorganic fertilizer (NPK: 15:15:15), and control) Each experimental site consists of 15 plots, each measuring 1 × 1 m, with a 0.5 m alley separating each of the plots. The layout of the experiment was a randomized complete block design (RCBD) with three replications.

Sources of organic amendments: The compost used was purchased from the Institute of Agricultural Research and Training (IART) in Ibadan, poultry manure was collected from the poultry section of Landmark University Teaching and Research Farm; *Tithonia diversifolia* was collected from Landmark University Teaching and Research Farm; and inorganic fertilizer (NPK: 15:15:15) and tomato seeds (Roman variety) were purchased from the agro-allied store Omu-Aran, Kwara State.

Land preparation, manure incorporation, seed sowing, and fertilizer application: Planting beds were made using a hoe. Experimental sites were laid out in 1 × 1 m plot sizes. Organic amendments were incorporated at a rate of 120 kg N/ha using a hoe to a depth of approximately 20 cm. The weight

Figure 1. Profile pit at the study area (site A).

Table 1. Initial Properties of Study Sites Prior to Planting.

SOIL PARAMETERS	SITE A	SITE B
pH in H_20	5.3b	7.3a
pH in $CaCl_2$	5.2b	6.5a
Exchangeable acidity(cmol/ kg)	2.9a	1.6b
Organic carbon (%)	1.1b	1.6a
Organic matter (%)	1.8b	2.8a
Available Phosphorus (mg/kg)	7.6b	24.5a
Calcium (cmol/kg)	3.0a	2.7b
Magnesium (cmol/kg)	1.3b	2.7a
Sodium (cmol/kg)	0.1a	0.01b
Potassium (cmol/kg)	0.12b	0.18a
Bulk density (g/cm^3)	1.53a	1.51b
Moisture content (%)	12.0b	14.0a
Porosity (%)	35.5b	36.2a
Particle size distribution		
Sand (%)	81.1	90.6
Silt (%)	7.0	4.0
Clay (%)	11.9	5.4
Textural class	Sandy loam	Sandy

Note. Means in a row under any given treatment followed by the same letter(s) do not differ significantly at 0.05 level of probability using the Duncan Multiple Range Test (DMRT).

of each amendment applied was compost (3.4 t/ha), poultry manure (4.2 t/ha), *Tithonia diversifolia* (4.8 t/ha), and NPK (0.8 t/ha). Before land preparation, the tomato seedlings (Roman variety seeds) were raised in the nursery at a temperature of about 23°C and watered daily. The plots were permitted for the mineralization of amendments before seedlings were transplanted. Transplanting was carried out at cool hours of the day, and each seedling was transplanted with some soil beneath to reduce damage to the seedling roots. Each seedling was transplanted at a spacing of 50 × 50 cm. NPK fertilizer was applied 10 cm away from the seedlings a week after transplanting, employing the side placement method. Manual weeding was done at intervals of 3 weeks after transplanting, and the tomato plants were staked at the fifth week after transplanting.

Soil sampling and laboratory analysis: Soil samples were obtained from the study site at 0 to 15 cm depth before and after the experiment. Soil pH was determined with an electronic soil pH metre (Model 215, Colorado, U.S.A.); soil particle size was analysed using the hydrometer method (Gee & Or, 2002); organic matter content was determined using the wet oxidation method (Shamshuddin et al., 1994); and exchangeable bases (K, Mg, Na, and Ca) were determined by the ammonium acetate method (Chapman, 1965). Organic amendment analysis: Samples of organic amendments (compost manure, poultry manure, and green manure) were taken for laboratory analysis. Chemical properties of amendments used are as stated in Table 2.

Microbial analysis (Plate Count of Cultivable Bacteria and Fungi): Soil samples were collected after the experiment into polythene bags at random using a soil auger and transported to the laboratory for a microbial count. The standard plate-count agar method was employed. Isolation of bacteria and fungi was done using Nutrient Agar (NA) and Potato Dextrose Agar (PDA), respectively. The fungi and bacteria populations were estimated using the six fold serial dilution method. The pour plate technique was used to culture fungi and bacteria from 10-3 to 10-5 soil dilutions, respectively. Incubation of PDA and NA was done at 37°C for 3 to 5 days and 24 hr at 28°C, respectively. Thereafter, the total number of cultivable bacteria, and fungi was counted as colony-forming units. The frequencies of occurrence of isolates were then calculated.

Morphological Characteristics of Bacteria and Fungi: Bacteria isolates were identified and enumerated with the aid of cultural characteristics and cell morphology, which include size, shape, colour elevation. Cultural morphological characteristics were also employed in the identification and enumeration of fungal isolates. These include colour, size, and pigment secretion. The soil microbial community diversity index was calculated using the following equation:

Shannon-Wiener index (H) :

$$H = \sum_{i=1}^{s} PiInPi$$

Pi is the ratio of the activity on a particular isolate to the sum of activities on all isolates; *S* is the sum of all isolate in one sample.

Statistical Analysis: To compare the means of the effects of the various treatments (independent variables) on the diversity

Table 2. Chemical Component of the Organic Amendments Used for the Study.

TREATMENTS	PARAMETERS					
	ORGANIC CARBON (%)	NITROGEN (%)	CALCIUM (CMOL/KG)	MAGNESIUM (CMOL/KG)	SODIUM (CMOL/KG)	POTASSIUM (CMOL/KG)
Compost	52.0a	3.5a	2.7a	4.9c	0.01a	0.4a
Poultry Manure	26.4b	2.9b	1.5c	5.7b	0.01a	0.3b
Tithonia diversifolia	17.4c	2.5c	1.7b	11.3a	0.01a	0.3b

Note. Means in a column under any given treatment followed by the same letter(s) do not differ significantly at the 0.05 level of probability using the Duncan Multiple Range Test (DMRT).

Table 3. Response of Soil Microbial (Bacteria and Fungi) Diversity and Total Number to Organic and Inorganic Soil Amendments at the Two Study Sites.

TREATMENTS	DIVERSITY OF BACTERIA (SITE A) (H)	DIVERSITY OF BACTERIA (SITE B) (H)	TOTAL NUMBER OF BACTERIA (CFU/G OF SOIL) (SITE A)	TOTAL NUMBER OF BACTERIA (CFU/G OF SOIL) (SITE B)	DIVERSITY OF FUNGI (SITE A) (H)	DIVERSITY OF FUNGI (SITE B) (H)	TOTAL NUMBER OF FUNGI CFU/G OF SOIL (SITE A)	TOTAL NUMBER OF FUNGI CFU/G OF SOIL (SITE B)
Compost	12	11	2,945	368	37	19	350	215
Poultry manure	21	18	740	1,406	24	18	127	146
Tithonia diversifolia	21	20	1,290	228	20	17	171	125
NPK	18	18	964	868	29	21	127	165
Control	17	19	159	991	20	16	75	101
Initial (Before Planting)	8	14	78	319	8	16	16	76

and population of soil bacteria and fungi (Dependent variables), collected data were subjected to analysis of variance (ANOVA) using IBM SPSS a statistical package (IBM Corp. Released, 2012).

Differences between significant means were separated by the Duncan multiple range test at the 0.05 level of probability. DMRT is a powerful tool that can be used to identify significant differences between means. However, it is important to note that it is also a conservative test, which means that it is less likely to find significant differences than other post hoc tests. This is because DMRT is designed to protect against Type I errors (false positives)

Results

Response of soil microbial (bacteria and fungi) diversity and total number to organic and inorganic soil amendments

Table 3 shows that, at site A, poultry manure had 21 diversity of bacteria, the same as *Tithonia diversifolia* (21), NPK (18), control (17), and compost had the lowest (12). However, at site B, *Tithonia diversifolia* had the highest bacteria diversity (20), followed by control (19), poultry manure (18), and compost, which had the lowest diversity (11). The order of total number of bacteria at site A is compost (2,945) >*Tithonia diversifolia* (1,290) >NPK (964) > poultry manure (740) > control (159), while at site B the total bacteria is in the order poultry manure (1,406) > control (991) >NPK (868) > compost (368) > initial (319) >*T. diversifolia*. For fungi, at site A, compost had the highest fungi diversity (37) followed by NPK (29), poultry manure (24), *Tithonia diversifolia* (20), and control (20). Compost also had the highest number of fungi (350), *Tithonia diversifolia* had (171), poultry manure and NPK had the same number of fungi (127) and control had the lowest (75), but the number of fungi at site B was compost (215) >NPK (165) > poultry manure (146), *Tithonia diversifolia* (125) > control (101) and the diversity of fungi at site B was in the order of NPK (21) > compost (19) > poultry manure (18) >*T. diversifolia* (17) > control (16) = initial (16).

Response of soil bacteria to the organic and inorganic amendments

Figure 2 shows the response of bacteria to the amendment applied at the study sites. The order of bacteria suppressed at site A is compost = NPK (30%) > control 20% > poultry

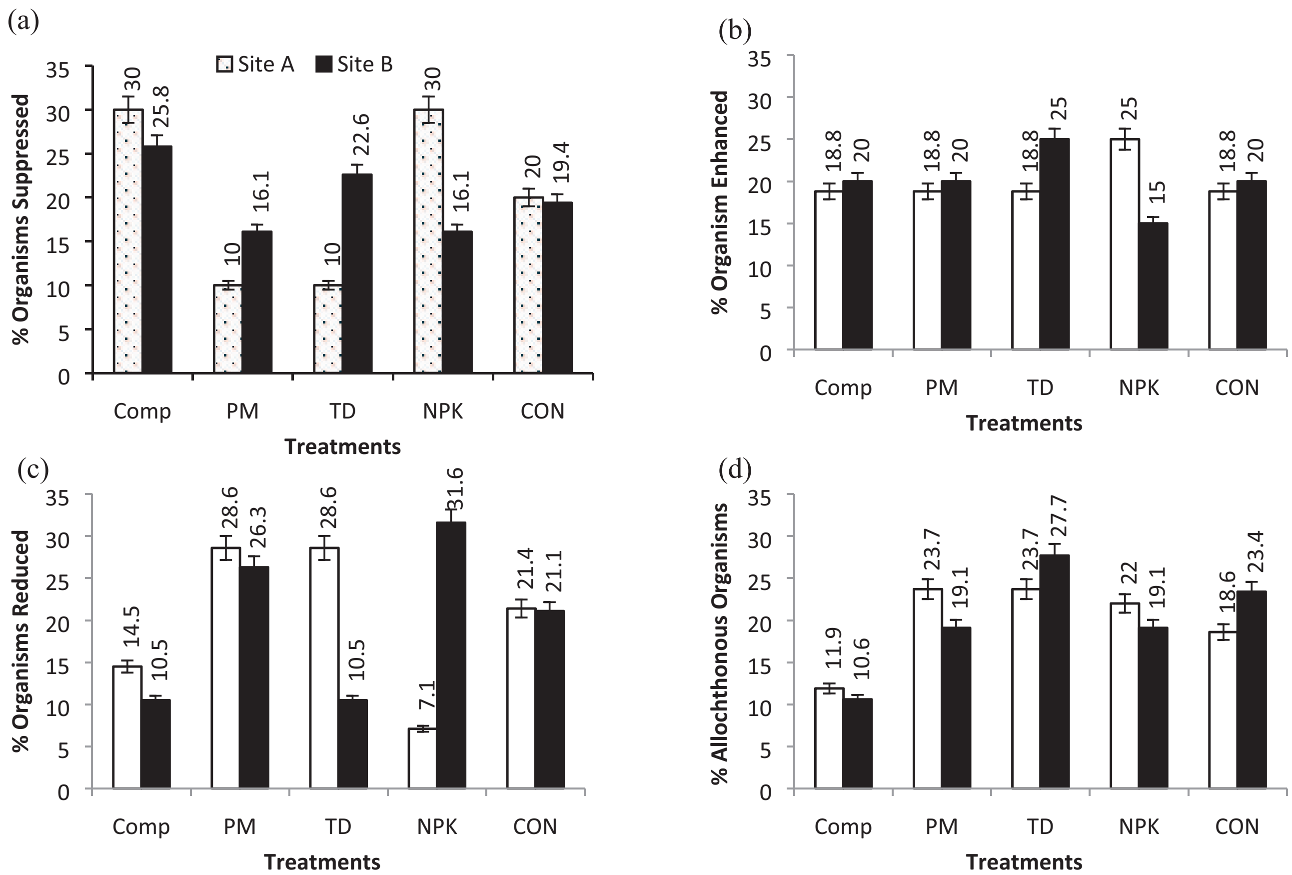

Figure 2. Response of soil bacteria to the organic and inorganic amendments: (a) % organisms suppressed, (b) % organisms enhanced, (c) % organisms reduced, and (d) % allochthonous organisms.
Note. Comp = compost; PM = poultry manure; TD = *Tithonia diversifolia*; CON = control.

manure = *T. diversifolia*, but at site B, the order of bacteria suppressed is compost 25.8% > *T. diversifolia* (22.6%) > control (19.4%) >NPK (16.1%) =PM (16.1%). The percentages of bacteria species whose growth was enhanced by the amendments were highest at plots amended with NPK (25%), compost, *T. diversifolia*, poultry manure and control were equal (18.8%) at site A, but at site B the order was *T. diversifolia* (25%) > compost =poultry manure = control (20%) >NPK (15%) For bacteria species whose growth was reduced by the amendments, at site A, Poultry manure = *T. diversifolia* (28.6%), and this was followed by control (21.4%), followed by compost (14.5%), and NPK had the least (7.1%). However, at site B, NPK (31.6%) had the highest percentage of bacteria species reduced, followed by poultry manure (26.3%), followed by control (21.1%), and compost = *T. diversifolia* (10.5%). The percentage of organisms that were not indigenous to the study site A was highest at plots amended with poultry manure and *T. diversifolia* (23.7%), followed by NPK (22%), followed by control (18.6%), and compost had the least (11.9%), but the order in site B is as follows: *T. diversifolia* (27.7%) > control (23.4%) > Poultry manure = NPK (19.1%) > compost (10.6%).

Suppressed organisms are organisms present in the soil at the commencement of the experiment but no longer present at the end of the experiment. Enhanced organisms are organisms whose population at the end of the experiment increased compared to their population at the commencement of the experiment. Reduced organisms are organisms whose population at the end of the experiment is reduced compared to their population at the commencement of the experiment. Allochthonous: these are organisms not present at all at the commencement of the experiment but present at the end of the experiment.

Response of soil fungi to the organic and inorganic amendments

According to Figure 3, the order of fungi suppressed in site A is: poultry manure =control (29.4%), >NPK (17.6%) > compost = *T. diversifolia* (11.8%), while, the order of fungi suppressed at site B is: *T. diverfolia* (28.2%) > poultry manure = control (23.1%) >NPK (12.8%) = compost (12.8%). The percentage of fungi enhanced at site A follows the following order: Compost = *T. diversifolia* = NPK = control (25%) > poultry manure (0%) while at site B it is as follows: compost (33.3%) = control > *T. diversifolia* (16.7%) >NPK (11.1%) > poultry manure (5.6%). At site A, the percentage of fungi organisms whose growth was reduced is in the order of compost = *T. diversifolia* (26.3%) >NPK (21.1%) > poultry manure (15.8%)

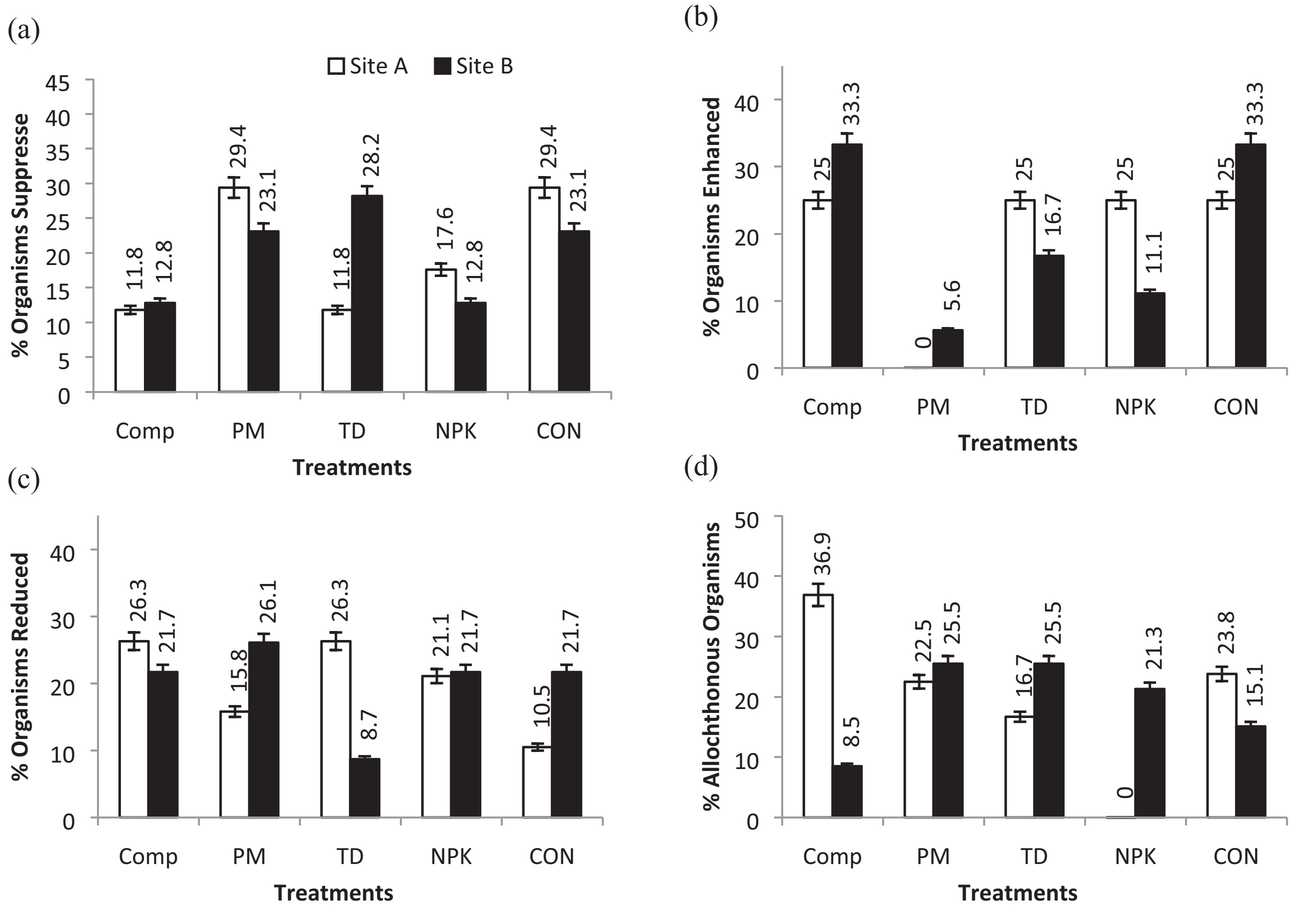

Figure 3. Response of soil fungi to the organic and inorganic amendments: (a) % organisms suppressed, (b) % organisms enhanced, (c) % organisms reduced, and (d) % allochthonous organisms.
Note. Comp = compost; PM=poultry manure; TD = *Tithonia diversifolia*; CON = control.

> control (10.5%), while at site B it is in the order of poultry manure (26.1%) >NPK = control = compost (21.7%) >*T. diversifolia* (8.7%). The percentage of Allochthonous fungi organisms follows the order of compost (26.9%) > control (23.8%) > poultry manure (22.5%) >*T. diverfolia* (16.7) >NPK (0%) while at site B it follows the order of poultry manure = *T. diversifolia* (25.5%) >NPK (21.3%) > control (15.1%) > compost (8.5%).

Suppressed organisms are organisms present in the soil at the commencement of the experiment but no longer present at the end of the experiment. Enhanced organisms are organisms whose population at the end of the experiment increased compared to their population at the commencement of the experiment. Reduced organisms are organisms whose population at the end of the experiment is reduced compared to their population at the commencement of the experiment. Allochthonous: these are organisms not present at all at the commencement of the experiment but present at the end of the experiment.

Effect of organic and inorganic amendment on growth parameters of tomato at the two study sites

The effect of amendments on the number of leaves on two soil types is shown in Table 4. The result shows that the number of leaves was not significantly different from each other at the two study sites at week 2. However, site A was significantly lower (45-0) than site B (264-1068.33) across the sampling weeks. The ANOVA response of amendments shows that the effect of the treatments applied on the number of leaves was significantly different across the weeks of sampling; however, there was no significant interaction between the study sites and the amendment used across the weeks. At week 2 after transplanting, control had a significantly higher number of leaves than other treatments. However, from weeks 4 to 8, compost had the highest significant number of leaves, followed by poultry manure, NPK, control, and *Tithonia diversifolia*. The table also shows the effects of amendments on the plant height of tomatoes planted at two sites. The analytical result shows that there was a significant difference at weeks 2 and 4 between the sites, with site B having a higher mean value (2.93–8.76 cm) than site A (2.24–0.00 cm) across weeks of sampling. The overall mean effect of amendments shows that there was a significant difference across the weeks of sampling. A significant difference was also observed in the sites and treatments interactions at 2 and 4 WAT. Among the amendments, *Tithonia diversifolia* was significantly different from all other treatments at 2 WAT; compost was significantly different from poultry manure; and poultry manure was significantly different from

Table 4. Effect of Organic and Inorganic Amendment on Growth and Yield of Tomato at the Two Study Sites.

	NUMBER OF LEAFLETS				PLANT HEIGHT (CM)				LEAF AREA(CM^2)				YIELD
SITES (S)	2 WAT	4 WAT	6 WAT	8 WAT	2WAT	4WAT	6WAT	8WAT	2WAT	4 WAT	6WAT	8 WAT	
Site A	30.77a	45.00b	9.60b	0.00b	2.24b	3.00b	5.13a	0.00b	4.24b	4.61b	7.20b	0.00b	10.67b
Site B	47.77a	264.00a	829.77a	1068.33a	2.93a	3.70a	5.05b	8.76a	4.76a	13.84a	19.49a	22.77a	456.28a
Treatments (A)													
Compost	53.61ab	317.83a	1062.78a	1187.78a	2.36b	2.80ab	6.11a	8.30b	5.53a	12.48a	20.61a	11.66bc	556.87a
Poultry manure	31.44bc	251.61ab	639.67b	775.33b	1.78c	2.36bc	4.98ab	10.91a	5.37a	12.48a	14.19ab	16.54ab	472.87ab
Tithonia diversifoliar	27.11c	87.00c	280.56c	364.89c	3.22a	4.11a	6.68a	6.21b	3.60a	7.40a	9.29b	18.97ab	226.35abc
NPK	30.78bc	162.78b	407.33bc	640.78bc	1.11d	1.62c	4.27ab	8.62ab	3.66a	9.80a	12.79b	21.68a	117.39bc
Control	67.56a	135.78bc	391.56bc	592.33bc	1.30cd	1.34d	3.34b	8.32b	4.79a	7.05c	8.12b	11.65bc	105.23c
ANOVA response													
S	0.09	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.83	0.00	0.00	0.00	0.00
A	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.39	0.37	0.015	0.00	0.04
S*A	0.11	0.49	0.06	0.23	0.00	0.01	0.12	0.71	0.66	0.81	0.51	0.30	.73

Note. WAT = weeks after transplanting.

NPK and control; however, NPK and control were not significantly different from each other. As observed from the table, *Tithonia diversifolia* had the highest value in weeks 2 and 4, followed by compost, poultry manure, NPK, and control. *Tithonia diversifolia* was significantly different from all other treatments except compost at week 4. Compost was not significantly different from poultry manure but from NPK and control. At week 6, compost and *Tithonia diversifolia* are significantly different from control but not significantly different from poultry manure and NPK, with *Tithonia diversifolia* having the highest value and control having the lowest. At 8 WAT, poultry manure was significantly higher than other treatments, while compost, *Tithonia diversifolia*, NPK, and control were not significantly different from each other. The effect of amendments on leaf area of tomatoes at 2, 4, 6, and 8 WAT in two sites is also presented in the table. The result showed that no significant difference was observed at 2WAT in the soil types, while a significant difference was observed from weeks 4 to 8. At weeks 6 and 8, significant differences were observed among the amendments used. However, there was no significant interaction between the sites and treatments used. The result also indicated that at week 2, all treatments were not significantly different from each other, with compost having the highest leaf area. At week 4, all the treatments were significantly different from the control, with compost and poultry manure having the highest differences. At 6 WAT, compost is significantly different from other treatments except poultry manure, while poultry manure is not significantly different from all other treatments. At week 8, NPK had the highest value and it was significantly different from all other treatments, *Tithonia diversifolia* was the second highest but not significantly different from compost, poultry manure, or control; however, control was the lowest. The mean value of yield also shows that site B has a significantly higher yield than site A. Among the treatments, compost had the maximum yield, while the lowest yield was recorded in control. Figure 4 shows tomato plant at both sites.

Effect of organic and inorganic amendment on soil chemical properties at the two study sites

Table 5 shows the effect of amendments on the chemical properties of the study sites. The chemical components of the study sites are significantly different from each other, as is the interaction between the soil types and amendments at $p < (.05)$ except for Calcium (Ca), Magnesium (Mg), and Phosphorus (P). Site B has higher components of OC, Ca, Mg, K, and P than site A, showing that site B is more fertile than site A. However, site A is higher than site B in Na and exchangeable acidity. The table further shows significant differences between the amendments used. The amendments increased the value of organic carbon in the soil. The values for organic carbon show that compost, poultry manure, and NPK are significantly different from *Tithonia diversifolia*, with the initial plot amended with compost having the highest value (1.83%). The table also shows that calcium content in the soil increased after amendment application and planting. The Ca content of all amended plots was significantly different from the initial value, with plots amended with compost having the highest value. The mean values for magnesium (Mg) show that *Tithonia diversifolia* is significantly different from all other treatments except initial and compost. All the treatments significantly increased the sodium content of the soil compared to the initial The mean value of potassium (K) shows that all the treatments increased the potassium content of the soil compared to the initial value. Compost and poultry manure significantly increased the available phosphorus (P) content of the soil, with compost having the highest available phosphorus. The application of amendments significantly reduced the exchangeable acidity of the soil. Site A is acidic in $CaCl_2$ (4.74) to slightly acidic in water (5.68), while site B is slightly acidic in $CaCl_2$ (6.49) to alkaline in water (7.44). The mean values of compost, poultry manure, and *Tithonia diversifolia* moderately increased the acidity of the soil, while NPK and control reduced the acidity of the soil.

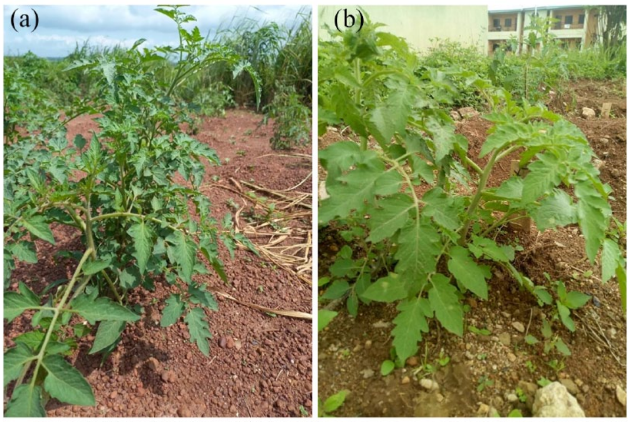

Figure 4. Tomato Crop at the study sites: (a) tomato crop at site A and (b) tomato crop at site B.

Discussion

Compost had the highest number of bacteria at site A and highest number and diversity of fungi at both sites this corroborate the findings of (Zhen et al., 2014), who stated that compost manure significantly increase the amount of cultivable microorganism. The increase in microbial diversity is beneficial for soil quality, noting that soil microorganisms play a key role in soil nutrient cycling. The highest number of cultivable and diversity of fungi in compost amended plots could be attributed to the significantly higher organic carbon of compost compared to other amendments, as shown in Table 2. All treatments increased both diversity of organisms and total numbers of organisms compared to the initial and control treatments. Organic amendments enhance the organic matter of soil, thereby providing

Table 5. Effect of Organic and Inorganic Amendment on Soil Chemical Properties.

SITES (S)	OC (%)	CA (CMOL/KG)	MG (CMOL/KG)	NA (CMOL/KG)	K (CMOL/KG)	EXC. ACD. (CMOL/KG)	P (MG/KG)	PH ($CACL_2$)	PH (WATER)
Site A	1.32b	2.10b	1.24b	0.04a	0.14b	1.22a	9.42b	4.74b	5.68b
Site B	1.76a	4.88a	2.23a	0.03b	0.17a	0.99b	23.83a	6.49a	7.44a
Treatments (A)									
Compost	1.83a	3.67ab	1.91ab	0.06a	0.19a	0.92b	30.62a	5.85b	6.95a
Poultry manure	1.73a	3.78ab	1.21b	0.031bcd	0.17b	0.89b	22.02b	5.89ab	6.98a
Tithonia	1.40b	4.43a	3.08a	0.038b	0.15c	0.81b	14.66bc	5.93ab	6.88a
NPK	1.69a	4.48a	1.63b	0.036bc	0.15c	0.76b	5.88b	6.83a	6.83a
Control	1.61ab	4.54a	1.32b	0.025d	0.12d	0.97b	5.78b	6.85a	6.85a
Intial	1.43b	2.80b	2.23ab	0.027cd	0.16bc	2.05a	6.07a	6.61b	6.61b
ANOVA response									
S	0.00	0.00	0.05	0.00	0.00	0.01	.00	0.00	0.00
A	0.00	0.04	0.05	0.00	0.00	0.00	.00	0.04	0.02
S*A	0.41	0.13	0.98	0.00	0.03	0.00	.98	0.05	0.04

nutrients and energy to the soil, which make the soil a favourable environment for crop growth and microorganism proliferation (Ansari R. A et al., 2019). Poultry litters are important for the functional and structural diversity of microbial populations (Mierzwa-Hersztek et al., 2018). Application of poultry manure increased the microbial biomass and significantly influenced the activity of nitrifying bacteria in the soil (Mierzwa-Hersztek et al., 2018). Control, despite not being amended, increased the number of bacteria and their diversity, which shows that the crop planted had a beneficial effect on the bacterial community through root exudates. Olanrewaju et al. (2019) further stressed that root exudates are an important factor that serves as a food source for soil microbes and plays a pivotal role in the interaction between plant and soil microbe.

The amendments affected the diversity and number of fungi present at study sites. The biotic and abiotic characteristics of compost in soil are indicators of high soil quality (Liu et al., 2009). According to Luo et al. (2022), most bacteria and fungi were detected after the incorporation of compost. High fungi diversity in poultry manure and *Tithonia diversifolia*-treated plots is a result of organic matter richness. In addition, changes in fungi were noticed when soil was amended with poultry manure (Abdullahi et al., 2013). Fungi diversity in NPK treated plots is highest, and this shows that fungi are sensitive to mineral fertilizer because it has the highest diversity in the study site. This result correlates with Zhong et al. (2010), who found higher amounts of fungal PLFA in NPK-treated soil. Soil microbial biomass and different community structures will increase with organic fertilization (Francioli et al., 2016). A higher nutritional component of compost has been reported by various researchers, which can support the growth of the encountered organisms (Antoniou et al., 2017).

The treatments suppressed the growth of some organisms, which could be associated with the antagonistic effect of the treatments and tomato plant root exudate (Shaji et al., 2021), indicating that microorganisms that grow from compost are either disease-suppressing organisms or beneficial organisms (Bahramisharif & Rose, 2019). The growth of some pathogenic fungi can be reduced in the soil during the mineralization of fresh poultry manure, which results in high heat production through ammonia. Some organisms were enhanced in the treated and control plots that were not present in the initial sample. This is in agreement with Farrell et al. (2010), who reported that compost addition had promoted enhanced microbial diversity. This was further corroborated by Strachel et al. (2017), who stated that compost application led to microbial growth intensification and increased biochemical activity in the soil as early as 2 weeks after compost application. This could be due to microbial and plant exudates, or they could be slow-growing organisms whose growth was only enhanced by treatment and root exudates, or they could be foreign organisms introduced by the treatments. According to Corning et al. (2016), organic amendments release organic matter into the soil, thereby increasing the microbial biomass, microbial activity, and production of polysaccharides in the soil. Plant root exudates are crucial for plant growth by releasing nutrients, changing soil pH, and enhancing some microbial diversity and activities (Antoniou et al., 2017). Some organisms occurred only in the initial samples. This could be as a result of nutrient consumption by the plant in control and/or as a result of microbial and plant exudates. This could also imply that all the treatments and the tomato plant do not support the growth and proliferation of these organisms. Some organisms occurred only during treatment. The occurrence of different organisms in these treatments could be a result of the different chemical compositions of the treatments. For instance, it was stated in Zhong et al. (2010) that fungi are sensitive to mineral fertilizers. Some organisms occurred only in control, and this shows that root exudates support the growth of microorganisms in the soil. According to Shaji et al. (2021), plant root exudates are important for plant growth and improving soil quality by releasing nutrients, changing soil pH, and enhancing some microbial diversity and activities.

Poultry manure had the least suppressed bacteria at both sites. This is in agreement with the findings of Sha et al. (2023), who reported that poultry manure is the best way to maintain an abundance of microorganisms. Poultry manure significantly improved soil microbial diversity (Minkina et al., 2022). Poultry manure mediates microbial richness because it confers the cycling of carbon, nitrogen, and sulphur, along with key soil enzymes such as dehydrogenases and catalase carbohydrate-active enzymes. Both soils influence the growth and yield of tomatoes differently (Table 4) because the soils differ in both physical and chemical properties. The soil from site B is significantly less bulky and less acidic compared to site A and also consists of significantly higher organic matter content, available phosphorus, and potassium. (Minkina et al., 2022).

Tithonia diversifolia produced the fewest leaves. This low performance of *Tithonia diversifoliar* can be due to its allelopathy attributes, which impose inhibitory effects on tomato leaf number. Allelochemicals released from allelopathy-attributed plants can be released through leaching, root exudation, volatilization, residue decomposition, and other processes in both natural and agricultural systems (Ferguson et al., 2013). As reported in Kato-Noguchi (2020), leaf residues of *Tithonia diversifoliar* causing inhibition of plant growth may be a result of unidentified allelopathic substances released into the soil by the decomposition of the leaf residues of *Tithonia diversifoliar*. O. O. Otusanya et al. (2007) studied the susceptibility of *Amaranthus crutusen* Linn to the phytotoxic effects of *Tithonia diversifoliar* and reported that the germination, growth parameters, and fresh and dry matter production of *Amaranthus crutusen* were retarded by all aqueous extracts applied. O. Otusanya and Ilori's (2012) results revealed that the germination and growth of the juvenile seedlings of test crops were significantly inhibited by the methanolic and water extract doses of *Tithonia diversifolia*.

More importantly, its low value may be due to its low organic matter content compared to compost and poultry manure (Table 2).

Among the treatments applied, compost significantly influenced the growth and yield parameters of tomatoes, followed by poultry manure. This could be due to their high nutrient composition (Table 2). The impact of organic and inorganic amendments on the growth of tomatoes has been reported by several researchers. Compost supplemented with *Jatropha* cake significantly increases the number of leaves of maize compared to NPK and control in a degraded soil (Olowoake et al., 2018). O. Fawole et al. (2016) studied the evaluation of two composts for the improvement of crop yield and reported that the composts improved the plant heights of tomatoes. This result is in line with the findings of Yagoub et al. (2012), who also reported that compost increased the plant height of soybeans. The application of compost increased the leaf area of fluted pumpkin, as reported by Umekwe (2020). In an experiment conducted by Musyimi et al. (2012), their result revealed that the aqueous shoot of *Tithonia diversifolia* increased the leaf area of the spider plant. O. Fawole et al. (2016) findings stated that compost improved the yield of tomatoes significantly. In the study of Yagoub et al. (2012), compost and other inorganic fertilizers were used to improve yield significantly.

From Table 5, it can be deduced that soil A has higher exchangeable acidity than site B making it more acidic than soil B. According to Stewart-Wade (2020), sodium concentration in a healthy and productive soil should be <1.0 meq/100g. The two soils are of moderate sodium concentration although; soil A is a bit higher than soil B which implies more salt concentration in soil A than soil B. Compost significantly increased the organic carbon of soil and this could be as a result high organic matter value of compost as recorded in Table 2. Goldan et al. (2023) reported that compost significantly increased the organic content of soil under field condition. Soil organic carbon promotes soil biological properties such as nutrient cycling and microbial enhancement as well as soil structure, aeration, water drainage and retention there by reducing soil risk to erosion and nutrient leaching (Corning et al., 2016). This also explains why compost had the highest significant value of total bacteria in study site A, total fungi in study sites A and B and diversity of fungi in site A as shown in Table 3. Application of poultry manure and NPK increased the organic carbon of the soil, which also corroborated results in Adekiya et al. (2020), and Adeyemo et al. (2019). The data obtained from Adeleye et al. (2010) indicated that poultry manure increased the organic matter of the soil. Hence, poultry manure has the highest bacteria diversity in study site A, total bacteria in study site B, and NPK has the highest diversity of fungi in the study site B.

Among all treatments, only *Tithonia diversifolia* increased the magnesium content of the soil, while others reduced it. This could be due to tomato plant's utilization of the nutrient. It was stated in research conducted by Quddus et al. (2021) that little or no magnesium results in low-quality tomato production. According to Kim et al. (2020), importance of magnesium in tomatoes ranges from vegetative growth to flowering to fruit ripening. The increase in *Tithonia diversifolia* could be attributed to its high Magnesium content, as shown in Table 2. All the treatments increased the potassium content of the soil, with control having the least, which could be due to plant uptake. The result from the table showed that all treatments increased the exchangeable bases. This result correlates with the findings of Adeleye et al. (2010), Ayeni and Ezeh (2017), Kobierski et al. (2017), Dayo-Olagbende et al. (2020), and Adekiya et al. (2020) who stated that the application of amendments increases the exchangeable bases in the soil. The application of amendments significantly reduced the exchangeable acidity of the soil. This result is in line with the findings of Becerra-Agudelo et al. (2022), and Onwuka et al. (2016). An increase in soil phosphorus content was supported by the reports of Adeleye et al. (2010), and Adekiya et al. (2020). The moderate increase in acidity of the soil can be a result of organic acids released during decomposition which further explains the enhancement of microbial population and diversity as shown in Table 3.

The increase in moisture content of the soil by all amendments could be due to an increase in organic matter, as shown in Table 5. Li et al. (2021) reported that the increase in fertility as a result of amendment application improved the moisture content of the sampled soil. This result is also corroborated by the findings of Mujdeci et al. (2019).

The soil bulk density prior to the start of the experiment was high; however, the application of treatments reduced the bulk density and hence increased the porosity of the soil. In a study conducted by Khalid et al. (2014), results showed that poultry manure reduced the bulk density and consequently increased the porosity of soil, as well as improving its stability. Bulk density reduction and porosity increase were observed in the experiment carried out by Agbede and Adebayo (2008). Adeleye et al.'s (2010) investigations on soil physico-chemical properties using poultry manure show that poultry manure reduced soil bulk density, temperature, and total porosity and increased soil moisture retention capacity. This trend was noticed in Agbede et al. (2013) and Kranz et al. (2020)

Conclusion

Compost improves both the total number and diversity of fungi better than other amendments, while the diversity of bacteria was improved more by poultry manure and *Tithonia diversifolia* than the other amendments studied. Plant exudates from tomatoes improved the growth of some soil microorganisms and reduced the growth of some other microorganisms. Effects of organic or inorganic amendments on soil microorganisms depend on the soil's physical and chemical properties. According to Minkina et al. (2022), chicken manure application significantly increased soil bacterial abundance under the nitrogen fertilization of 135 and 225 kg hm^{-2}, increased soil fungal abundance under the nitrogen fertilization of 135 kg hm^{-2}, but decreased soil fungal abundance under the nitrogen fertilization of 180 and 225 kg hm^{-2}. To improve the microbial properties of soil, compost, poultry manure, and *Tithonia diversifolia* are recommended.

Understanding the specific effects of organic and inorganic amendments on individual microbial species can be challenging due to the complexity of soil microbial communities. The response of soil microbial communities to amendments can depend on several factors, such as climate, agricultural management practises, and the specific type and amount of amendment used. Thus, results from one location or under specific conditions may not be directly applicable to other situations.

Authors Contributions

ETA conceptualized the research, supervised the research and wrote the main text. FTO carry out the research and wrote part of the main text. AOA co- supervised the research. AJ and KAA co-supervised the research. AI constructs the figures and tables. COA and OOB reviewed and supervised the writing of the manuscript.

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Data Availability Statement

All data are included in this manuscript.

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