

**THE RESIDUAL EFFECT OF SOME ORGANIC AMENDMENT ON THE PHYSICAL,  
CHEMICAL AND MICROBIAL PROPERTIES OF SOILS PREVIOUSLY CULTIVATED  
WITH BELL PEPPER**

**BY**

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## CERTIFICATION

This is to certify that this research was carried out by **Tracy Okeoghene OBARO** under the guidance of the project supervisor and approved by the Department of Soil Science and Land Management, Faculty of Agriculture, University of Benin, Benin City, Edo State, Nigeria.

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## DEDICATION

To my beloved mother Mrs Charity Obaro, I sincerely appreciate you, for giving me the enablement and providing the resources to undertake this important journey and also for being a source of encouragement through it all. I also dedicate this Research project to God Almighty who has indeed been my source, sustainer and guidance throughout this journey.

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## ABSTRACT

This study investigated the residual effects of selected organic amendments on the physical, chemical, and microbial properties of soils previously cultivated with bell pepper (*Capsicum annuum* L.). The experiment was laid out in randomised block design (RCBD) with twelve different treatment representing sole treatment (T1(control) T2 (Poultry manure) T3 (Mychorriza) T4( Black soldier fly frass) T5 (Digestate) and the rest as combined treatments. This research compared data from soil samples collected from the previous cultivation season in 2024 with soil samples of the post harvest period (2025) to evaluate changes in soil quality, the continuous and sustained effects of amendments over time. The results from the analysis shows that There was a decrease in pH from 2024 to 2025, from (6.47 to 6.00) in T2(PM), while organic matter and organic carbon showed a general increase from (5.30 to 34.60 g/kg) and (3.10 to 20.10 g/kg) in T12(DIG+PM) respectively. In comparing 2024 and 2025, bacterial counts increased across all treatments, while fungal counts declined. Results revealed that while some nutrient parameters declined compared to the initial season (2024 cropping season), soils that previously received combined organic treatments maintained significantly improved fertility indices relative to the control. These findings demonstrated that the amendments not only improved soil fertility during the first year but also had lasting residual benefits that continued enhancing the soil even without re-application.

Also this study recognizes T12(DIG +PM) as the best most sustainable amendments because it effectively balanced nutrient supply, organic matter input, and microbial stimulation leading to enhanced soil fertility and lasting residual effects.

Keywords: Poultry manure, Digestate.

## CHAPTER ONE

### 1.0 INTRODUCTION

Bell pepper (*Capsicum annuum* L.), commonly known as sweet pepper, is among the most widely cultivated vegetable crops worldwide due to its high economic importance and nutritional quality. It is valued for its diverse use in fresh and processed forms and its contribution to food security and income generation for small-scale farmers (Guijarro *et al.*, 2023). Nutritionally, bell pepper is rich in essential vitamins such as A, C, and E, as well as bioactive compounds including carotenoids, flavonoids, and phenolic acids, which possess strong antioxidant properties (Olatunde *et al.*, 2021). It also provides significant amounts of dietary fiber, potassium, calcium, and magnesium, making it a vital component of a balanced human diet (Kowalska *et al.*, 2020).

Residual effects of organic amendments refer to the long-term impacts these materials have on soil and plant health after their initial application, often across subsequent cropping seasons (Diacano *et al.*, 2015). Even after the first crop has been harvested, the decomposition and nutrient release from the organic materials continue to influence soil fertility, structure, and microbial activity. (Liu *et al.*, 2022)

Long-term continuous cropping alters soil chemical properties and microbial community structure, often reducing beneficial microbes and increasing pathogenic ones, which contributes to soil degradation and lower crop yield. This degradation results from nutrient depletion, changes in enzyme activity, and microbial imbalance produced by repeated monocropping without proper soil management (Agomoh *et al.*, 2018).

To combat these challenges, the use of organic amendments (such as poultry manure, compost, farmyard manure, and green manures) has gained popularity as a sustainable alternative to chemical fertilizers. (Wang *et al.*, 2022)

While many studies have documented the immediate benefits of these amendments during crop growth, less attention has been given to their residual effects that is, the sustained influence these materials have on soil health after the cropping season has ended (Zhang *et al.*, 2018).

## **1.1 Research Objective**

The main objective of this research was to:

1. Compare the residual impact of different types of organic treatment on soil properties
2. Evaluate the residual effects of various organic amendments on soil microbial communities.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Organic Amendments and Their Residual Effect in Sustainable Soil Management

Organic amendments serve as essential nutrient sources and microbial substrates, thereby boosting soil fertility and supporting plant growth (Panotra *et al.*, 2024). Their application improves soil structure, increases water retention, enhances microbial activity, and reduces erosion risk (Virto *et al.*, 2022). The continuous use of organic amendments contributes to the formation of stable soil organic matter and humus, aiding in carbon sequestration and climate mitigation (Singh *et al.*, 2024). These practices embody circular economy principles by converting agricultural wastes into valuable soil inputs.

In tropical agronomic systems often degraded by intensive cultivation and erosion the addition of organic amendments enhances microbial diversity and enzymatic activity, further strengthening soil fertility (Panotra *et al.*, 2024).

The synergy between organic residues and soil microorganisms supports biological nutrient processes, such as nitrogen fixation, and improves soil buffering capacity. By increasing soil organic carbon, these amendments sustain microbial diversity and long-term soil productivity (Panotra *et al.*, 2024)

The concept of the “residual effect” refers to the lasting influence of organic amendments on soil health and plant performance beyond the initial cropping season. This effect is especially valuable in low-input farming systems where frequent applications may be economically impractical. Organic amendments

improve soil structure, stimulate microbial activity, and provide gradual nutrient release across multiple planting cycles. Through the progressive buildup of organic matter and beneficial microorganisms, residual effects enhance soil resilience, nutrient cycling, and counteract degradation over time (Virto *et al.*, 2022).

### 2.1.2 Microbial Properties of Soils with Residual Organic Amendments

Soil microbial attributes such as microbial biomass, enzyme activities, microbial community diversity, and metabolic functions are central to the processes that sustain soil fertility and productivity. These parameters respond quickly to management practices and serve as early indicators of soil health improvement or degradation (Jia *et al.*, 2025). Organic materials added to the soil act as both nutrient sources and habitats for microorganisms, thereby enhancing microbial biomass and diversity through improved energy and carbon inputs (Li *et al.*, 2024).

Even after the primary crop harvest, residual organic matter maintains microbial activity, supporting continuous nutrient mineralization and organic matter turnover. Long-term organic amendment studies reveal sustained increases in soil enzyme activities, such as  $\beta$ -glucosidase and urease, alongside greater microbial biomass carbon and nitrogen (Wang *et al.*, 2023). However, microbial responses vary with amendment type, application timing, and inherent soil properties emphasizing the need for site-specific organic management strategies (Peng *et al.*, 2024).

Residual organic materials build microbial carbon and nitrogen pools, which are vital for nutrient cycling (Li *et al.*, 2023). Their presence stimulates enzyme activities that break down complex organic compounds into plant-available forms, enhancing nutrient uptake efficiency (Sun *et al.*, 2025). Over time, soils enriched with organic inputs show higher microbial diversity and greater resilience to stress, such as

drought, compared to conventionally managed soils (Chen *et al.*, 2024). Moreover, organic amendments foster beneficial organisms such as arbuscular mycorrhizal fungi (AMF) and nitrogen-fixing bacteria (e.g., *Rhizobium* and *Azospirillum*), which further enhance soil health and plant nutrient acquisition (Gao *et al.*, 2024).

## 2.2 Influence on Subsequent Crop Performance

Soils amended with organic materials possess superior nutrient profiles, enhanced biological activity, and improved structure, creating an environment conducive to sustained agricultural productivity (Xu *et al.*, 2024). Field studies have demonstrated that crops planted after organic amendment applications exhibit improved germination, stronger vegetative growth, and higher yields compared to those grown on conventionally fertilized or unfertilized soils (Zhou *et al.*, 2024).

The structural improvements induced by organic inputs such as increased aggregation, porosity, and water-holding capacity facilitate deeper root penetration and better nutrient and water uptake (Liu *et al.*, 2023). These properties also buffer crops against drought stress, which is critical in rain-fed systems (Temesgen *et al.*, 2023).

Beyond the direct nutrient benefits, organic amendments improve the soil's biological integrity, fostering microbial communities that suppress pathogens and enhance beneficial plant-microbe interactions, thereby reducing disease incidence in subsequent crops (Huang *et al.*, 2024). In some cases, organic residues release allelopathic compounds that suppress weed germination, reducing competition for water and nutrients and lowering herbicide dependency (Kundu *et al.*, 2023). Additionally, their slow decomposition ensures a steady nutrient release throughout the cropping cycle, supporting consistent plant growth (Alabi *et al.*, 2023).

### 2.2.1 Changes in Soil Physical and Chemical Properties of soil Over Time

Organic amendments such as compost, poultry manure, and green manures play a crucial role in modifying the physico-chemical properties of soils. These changes are not only immediate but also persist over time, influencing subsequent crop productivity and soil resilience (Liu *et al.*, 2022). In particular, such amendments have been shown to improve soil structure, reduce bulk density, increase water-holding capacity, and enhance nutrient availability (Zhao *et al.*, 2021). Particularly in fields previously cultivated with bell pepper, understanding these transformations helps guide effective amendment management strategies (Sánchez-García *et al.*, 2015).

### 2.2.2 The chemical benefits of organic amendments include:

**Increased soil organic carbon (SOC):** Organic amendments such as compost and vermicompost contribute high levels of organic matter, which increase the soil organic carbon content. This enrichment improves soil fertility and nutrient retention.

**Improved cation exchange capacity (CEC):** The addition of organic matter enhances the soil's ability to hold and exchange essential nutrient cations, which supports better nutrient availability to plants.

**Buffering of soil pH:** Organic amendments can help buffer soil pH, often raising acidic soils closer to neutral by adding materials with higher pH values. This buffering improves the soil environment for microbial activity and nutrient availability.

**Enhanced macro and micronutrient availability:** Regular application of organic amendments increases the availability of nutrients such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and trace elements by adding organic sources and improving soil chemical properties

For instance, Rehman *et al.* (2016) demonstrated that poultry manure and green manure not only increased nitrogen (N), phosphorus (P), and potassium (K)

availability in the first year but also had carry-over effects that improved the chemical fertility of soils cultivated to vegetables in subsequent seasons.

In bell pepper cultivation, Pane *et al.* (2019) showed that the residual effects of compost and biochar improved nutrient retention and supported healthy microbial populations one year after the initial application, indicating sustained improvements in soil chemical properties.

### **2.3 Effects of organic amendments on:**

#### **Soil pH, Buffering Capacity, and Cation Exchange Capacity (CEC)**

Soil pH is a critical determinant of nutrient availability and microbial activity. Organic amendments can shift soil pH, either increasing it in acidic soils or buffering it in neutral to slightly alkaline conditions. For instance, composts rich in calcium and magnesium have been shown to raise acidic soil pH by up to 1.5 units (Agbede *et al.*, 2017).

Buffering capacity is also improved, enabling soils to resist rapid pH fluctuations during fertilization or heavy rain. Furthermore, Organic matter enhances cation exchange capacity (CEC), improving nutrient retention in soils. For instance, application of poultry manure has been demonstrated to increase CEC significantly even by 10–20% or more after one or two cropping seasons depending on soil texture (Poblete-Grant *et al.*, 2023) The magnitude of these improvements is strongly influenced by soil texture, with coarse-textured soils showing notable increases in exchangeable bases and effective CEC upon manure addition (Joseph *et al.*, 2025). Sandy soils respond more rapidly to organic inputs in terms of pH changes, whereas clayey soils show more persistent effects due to their intrinsic buffering abilities. Thus, in bell pepper fields, amendment choice and soil type must be considered to avoid micronutrient deficiencies or toxicities linked to abrupt pH changes.

## **2.4 Nutrient Availability Dynamics for soils with organic amendments**

One of the most important physical and chemical transformations from the use of organic amendment is the gradual and sustained availability of nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients. Unlike synthetic fertilizers, organic inputs release nutrients slowly as they decompose, leading to a residual effect that benefits subsequent crops.

(Agbede *et al.* 2014) found that compost application in a bell pepper rotation system increased available P and K by 45% and 30% respectively, two months after application, and maintained elevated levels up to six months later. However, the exact timing and amount of nutrient availability depend on the type and maturity of the organic material. Fresh manure releases N rapidly, while composted materials offer more prolonged nutrient release due to stabilized organic compounds (Chukwuka *et al.* 2016).

Micronutrient availability, especially for zinc (Zn), copper (Cu), and boron (B), is enhanced in soils treated with manure and compost due to complexation with organic acids. However, excessive application can lead to nutrient imbalances or leaching, particularly in light-textured soils or areas with high rainfall.

## **2.5 Influence of Organic Amendments on Soil Nutrient Critical Levels**

Organic amendments play a vital role in modifying soil nutrient critical levels by enhancing nutrient bioavailability, improving buffering capacity, and stimulating microbial activity. They contribute to soil fertility through the gradual release of nutrients, increased cation exchange capacity (CEC), and regulation of soil pH (Aytenuw *et al.*, 2020). Repeated applications of poultry manure have been shown to increase soil phosphorus availability and reduce the amount of inorganic P fertilizer required to achieve sufficiency levels, indicating that organic inputs can redefine

nutrient critical thresholds (Obi *et al.*, 2022). Likewise, compost and manure amendments improve soil structure, boost microbial mineralization, and facilitate the steady release of nitrogen and micronutrients for plant uptake (Ng'etich *et al.*, 2023). These studies suggest that nutrient critical levels derived from inorganic fertilizer trials may not be directly applicable to organically managed soils. Furthermore, the accumulation of organic matter supports nutrient synchronization with crop demand, enhances nutrient use efficiency, and minimizes nutrient losses through leaching or volatilization (Oyedeji *et al.*, 2024).



## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

#### 2024 cropping season

3

### 3.2 Residual study (2025 Post harvest)

#### 3.2.1 Soil Sampling Date and Procedure for the residual effects

Soil samples were collected from each treatment plot on 26th April 2025 to assess the residual effects of organic amendments after bell pepper cultivation. Samples were systematically taken from the plant stands representing different treatments, following a standardized protocol to ensure consistency across replicates.

#### **Preparation of Soil Samples for Laboratory Analysis**

Soil samples were stored in clean, labeled containers and immediately transported to the laboratory for analysis. Standard procedures were followed to prepare the samples for physical, chemical, and microbial assessments.

### 3.2.2 Number of Treatments and Application Rates Per Bed

1	Control (no amendment)	0
2	Poultry Manure (PM)	516 g
3	Mycorrhiza (MY)	1 g
4	Black Soldier Fly Frass (BFF)	643 g
5	Digestate derived from cattle rumen (DIG)	10 L
6	Digestate + Poultry Manure + Mycorrhiza + Black fly frass (DIG+PM+MY+BFF)	DIG (25%) + PM (50%) + MY (1 g) + BFF (25%) = 2.5 L + 258 g + 1 g + 160.75 g
7	Poultry Manure + Mycorrhiza + Black fly frass (PM+MY+BFF)	PM (50%) + MY (1 g) + BFF (50%) = 258 g + 1 g + 312.5 g
8	Mycorrhiza + Black fly frass + Digestate (MY+BFF+DIG)	MY (1 g) + BFF (50%) + DIG (50%) = 1 g + 312.5 g + 251 mL
9	Digestate + Mycorrhiza (DIG+MY)	DIG (100%) + MY (1 g) = 10 L + 1 g
10	Black fly frass + Digestate (BFF+DIG)	BFF (50%) + DIG (50%) = 312.5 g + 5 L
11	Mycorrhiza + Black fly frass (MY+BFF)	MY (1 g) + BFF (100%) = 1 g + 643 g
12	Digestate + Poultry Manure (DIG+PM)	DIG (50%) + PM (50%) = 5 L + 258 g



### 3.3 Soil Physical and Chemical Analysis

#### 3.3.1 Soil pH Determination (Electronic pH Meter Method)

Twenty grams (20 g) of fine tilth soil sample was weighed into a 50 ml beaker, and 40 ml of distilled water was added. The mixture was stirred intermittently for 30 minutes. Soil pH was then measured using a standardized electronic pH meter and recorded as pH 1:2 in H<sub>2</sub>O (Sonkar and Kumar, 2022).

#### 3.3.2 Percentage Organic Carbon Determination (Walkley-Black Method)

One gram (1 g) of soil sample was weighed into a 250 ml conical flask. Ten milliliters (10 ml) of 1N potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>) was added and swirled for proper mixing. Then, 20 ml of concentrated sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) was carefully added and mixed. The sample was left for 30 minutes. A 100 ml volume of distilled water was then added and the mixture swirled. Five drops of ferroine indicator were added, and the excess chromic acid was titrated with 0.5 N ferrous sulfate till the endpoint was reached.

% Organic carbon was calculated using the formula:

$$\text{Where: } \frac{(B-T) \times N \times F \times 0.003 \times 100}{W}$$

Where:

- B = blank titre value
- T = sample titre value
- N = normality of ferrous sulfate
- F = correction factor (1.33)
- W = weight of soil sample used

(Sun et al., 2020)

### 3.4 Nitrogen Determination (Kjeldahl Method)

#### Digestion:

One gram (1 g) of air-dried soil was placed in a Kjeldahl digestion flask. One catalyst tablet (containing  $\text{CuSO}_4$ ,  $\text{K}_2\text{SO}_4$ , and selenium) and 20 ml of concentrated  $\text{H}_2\text{SO}_4$  were added. The mixture was heated until clear (light green color) and then cooled. About 10 ml of water was added, then filtered into a 100 ml volumetric flask and made up to volume.

#### Distillation:

A 10 ml aliquot of digest was transferred to the distillation unit. Thirty milliliters (30 ml) of water and 15 ml NaOH (excess base) were added, heated, and 2.5 ml distillate collected into 5 ml boric acid indicator. The  $\text{NH}_4$ -Nitrogen was titrated with 0.01 M HCl until color changed from green to pink.

% Nitrogen was calculated as:  $W \times M \times \frac{14}{1000} \times \frac{V_1}{V_2} \times \frac{100}{W}$

Where:

- T = titre value
- M = molarity of HCl
- $V_1$  = final volume of digest
- $V_2$  = volume of aliquot used for distillation
- W = weight of sample

(Ibitoye, 2008)

## Screening for Plant Growth Promoting Properties of Fungal Isolates

### Phosphate Solubilization Activity

Fungal isolates were cultured in replicates on Pikovskaya's agar plates and incubated at 30°C for 3 days. Clear zones around colonies observed after 13 days indicated phosphate solubilization.

The solubilization index (SI) was calculated using the formula:

$$SI = \frac{\text{Halo zone diameter} + \text{Colony diameter}}{\text{colony diameter}}$$

(Doilom et al., 2020)

### 3.6.2 Statistical analysis

Data obtained was subjected to analysis of variance (ANOVA) using GenStat 20th Edition (VSN International, 2019) and means would be separated by Least significant difference (LSD) test.



## CHAPTER FOUR

### 4.1 Results and discussions

#### 4.1.1 The Residual effect of the amendment on the physical and chemical properties of the soil

A significant increase in soil pH was recorded in T11 (6.01) compared to the control T1 (5.80). This indicates the combined effect of mycorrhiza and black fly frass, which likely contributed to a liming effect by the release of basic cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^{+}$ ) from organic residues (Table 1) Houben *et al.* (2022) reported similarly that insect frass and organic amendments raise soil pH by neutralizing exchangeable acidity and supplying nutrient bases. The observed electrical conductivity (EC) values, which were generally higher in amended plots than in the control, further indicate an increase in soluble salts resulting from amendment mineralization. Among the treatments, T12 (digestate + poultry manure) had the highest EC value (485.70  $\mu\text{S}/\text{cm}$ ), reflecting the high nutrient and ion content of poultry manure and digestate, both of which are rich in readily mineralizable organic matter (Agbede *et al.*, 2024). In contrast, T8 (mycorrhiza + black fly frass + digestate) showed the lowest EC value (247.00  $\mu\text{S}/\text{cm}$ ), which may be attributed to greater nutrient uptake by plants or possible leaching losses. Similar findings were reported by Zhao *et al.* (2025), they noted that manure-based amendments increase EC and nutrient availability, while differences across treatments depend on amendment type and decomposition rate.

## 4.2 Physical and chemical statistical analysis of soil after harvesting bell pepper

Treatments	Ph (1:1)	EC Us/cm	O.C Us/cm	O.M Us/cm	T.N Us/cm	AV.P Mg/kg	K Cmol/kg	Mg Cmol/kg	Na Cmol/kg	EA Cmol/kg	ECEC	B.S %	Sand g/kg	Silt g/kg	Clay g/kg	texture
T1	5.80 <sup>c</sup>	308.00 <sup>i</sup>	14.50 <sup>l</sup>	24.97 <sup>l</sup>	1.30 <sup>c</sup>	1.21 <sup>l</sup>	0.28 <sup>h</sup>	0.14 <sup>bc</sup>	0.08 <sup>bc</sup>	1.00 <sup>b</sup>	1.72 <sup>bc</sup>	41.75 <sup>d</sup>	871.00 <sup>a</sup>	10.00 <sup>a</sup>	119.00 <sup>a</sup>	L.S
T2	6.00 <sup>a</sup>	313.00 <sup>h</sup>	14.77 <sup>h</sup>	25.43 <sup>h</sup>	1.30 <sup>c</sup>	1.32 <sup>h</sup>	0.20 <sup>k</sup>	0.10 <sup>c</sup>	0.05 <sup>d</sup>	0.70 <sup>bc</sup>	1.20 <sup>e</sup>	41.83 <sup>d</sup>	878.00 <sup>a</sup>	8.00 <sup>b</sup>	120.00 <sup>a</sup>	L.S
T3	6.00 <sup>a</sup>	363.00 <sup>d</sup>	17.35 <sup>d</sup>	29.93 <sup>d</sup>	1.57 <sup>ab</sup>	1.71 <sup>d</sup>	0.41 <sup>d</sup>	0.20 <sup>b</sup>	0.11 <sup>b</sup>	0.63 <sup>c</sup>	1.65 <sup>cd</sup>	61.74 <sup>a</sup>	866.00 <sup>a</sup>	11.00 <sup>a</sup>	123.00 <sup>a</sup>	L.S
T4	5.70 <sup>d</sup>	295.30 <sup>j</sup>	14.00 <sup>j</sup>	24.10 <sup>j</sup>	1.30 <sup>c</sup>	1.10 <sup>k</sup>	0.22 <sup>j</sup>	0.11 <sup>bc</sup>	0.07 <sup>c</sup>	1.13 <sup>a</sup>	1.67 <sup>c</sup>	32.30 <sup>e</sup>	873.00 <sup>a</sup>	8.00 <sup>b</sup>	119.00 <sup>a</sup>	L.S
T5	5.63 <sup>e</sup>	343.00 <sup>e</sup>	16.20 <sup>e</sup>	27.90 <sup>e</sup>	1.50 <sup>b</sup>	1.63 <sup>e</sup>	0.40 <sup>e</sup>	0.20 <sup>b</sup>	0.11 <sup>b</sup>	1.10 <sup>a</sup>	2.13 <sup>b</sup>	48.27 <sup>c</sup>	872.00 <sup>a</sup>	7.00 <sup>b</sup>	121.00 <sup>a</sup>	L.S
T6	5.70 <sup>d</sup>	385.00 <sup>c</sup>	17.80 <sup>c</sup>	30.60 <sup>c</sup>	1.60 <sup>ab</sup>	1.84 <sup>c</sup>	0.44 <sup>c</sup>	0.21 <sup>a</sup>	0.12 <sup>a</sup>	1.00 <sup>b</sup>	2.12 <sup>b</sup>	52.53 <sup>b</sup>	862.00 <sup>a</sup>	8.00 <sup>b</sup>	124.00 <sup>a</sup>	L.S
T7	5.80 <sup>c</sup>	299.00 <sup>j</sup>	14.10 <sup>j</sup>	24.30 <sup>j</sup>	1.30 <sup>c</sup>	1.17 <sup>j</sup>	0.25 <sup>i</sup>	0.12 <sup>bc</sup>	0.07 <sup>bc</sup>	1.00 <sup>b</sup>	1.63 <sup>d</sup>	38.77 <sup>e</sup>	870.00 <sup>a</sup>	11.00 <sup>a</sup>	119.00 <sup>a</sup>	L.S
T8	6.00 <sup>a</sup>	247.00 <sup>k</sup>	13.30 <sup>k</sup>	22.90 <sup>k</sup>	1.20 <sup>d</sup>	1.04 <sup>l</sup>	0.21 <sup>k</sup>	0.10 <sup>c</sup>	0.06 <sup>c</sup>	0.60 <sup>c</sup>	1.13 <sup>e</sup>	46.90 <sup>c</sup>	892.00 <sup>a</sup>	10.00 <sup>a</sup>	118.00 <sup>a</sup>	L.S
T9	5.70 <sup>d</sup>	446.00 <sup>b</sup>	19.87 <sup>b</sup>	34.23 <sup>b</sup>	1.80 <sup>a</sup>	2.10 <sup>b</sup>	0.48 <sup>b</sup>	0.23 <sup>a</sup>	0.13 <sup>a</sup>	1.10 <sup>a</sup>	2.30 <sup>a</sup>	52.17 <sup>b</sup>	863.00 <sup>a</sup>	11.00 <sup>a</sup>	126.00 <sup>a</sup>	L.S
T10	5.90 <sup>b</sup>	321.00 <sup>g</sup>	15.30 <sup>g</sup>	26.30 <sup>g</sup>	1.40 <sup>bc</sup>	1.43 <sup>g</sup>	0.33 <sup>g</sup>	0.16 <sup>bc</sup>	0.09 <sup>bc</sup>	1.00 <sup>b</sup>	1.82 <sup>bc</sup>	45.05 <sup>c</sup>	872.00 <sup>a</sup>	8.00 <sup>b</sup>	120.00 <sup>a</sup>	L.S
T11	6.01 <sup>a</sup>	339.00 <sup>f</sup>	16.00 <sup>f</sup>	27.50 <sup>f</sup>	1.50 <sup>b</sup>	1.51 <sup>f</sup>	0.39 <sup>f</sup>	0.19 <sup>bc</sup>	0.10 <sup>bc</sup>	0.50 <sup>d</sup>	1.46 <sup>e</sup>	65.68 <sup>a</sup>	873.00 <sup>a</sup>	7.00 <sup>b</sup>	120.00 <sup>a</sup>	L.S
T12	5.91 <sup>b</sup>	485.70 <sup>a</sup>	20.10 <sup>a</sup>	34.60 <sup>a</sup>	1.80 <sup>a</sup>	2.14 <sup>a</sup>	0.51 <sup>a</sup>	0.25 <sup>a</sup>	0.14 <sup>a</sup>	1.00 <sup>b</sup>	2.28 <sup>a</sup>	56.20 <sup>a</sup>	863.00 <sup>a</sup>	8.00 <sup>b</sup>	129.00 <sup>a</sup>	L.S

KEYWORD: EC-electronic conductivity, OC -organic carbon, OM-organic matter, TN- total nitrogen, AV-P-available Phosphorus, B.S - base saturation, EA-Exchangeable acidity

The organic carbon ranges from the highest in T12(DIG + PM) to lowest T8 (MY+BFF+DIG ) which are 20.10g/kg and 13.30g/kg respectively. This indicates that the application of poultry manure encourages the presence of organic carbon and organic manure which aligns with the study done by (Agbede et al.,2024) Who found that poultry manure significantly increased soil organic carbon and other fertility attributes in their experiment.

All amended treatments significantly ( $P \geq 0.05$ ) improved soil organic carbon (OC) and organic matter (OM) compared to the control. Poultry manure (T2) and digestate (T5) had the highest improvements, while treatments combining black fly frass with mycorrhiza and biofertilizer (T7, T8, T9) also showed significant enrichment. Organic amendments contribute directly to soil carbon pools and enhance soil structure(Chen *et al.*,2024).

Treatments involving poultry manure, mycorrhiza and digestate (T3, T9, T6, T12) significantly ( $P \geq 0.05$ ) increased with values (1.57, 1.60,1.80,1.80 mg/kg) of total nitrogen compared to the control at 1.30mg/kg Mycorrhiza-amended treatments (T3, T6, T9, T12) were particularly effective in enhancing available phosphorus, likely due to increased root and fungal interactions and solubilization of bound P. This agrees with (Gao *et al.*,2024), They found that mycorrhiza inoculation increases phosphorus uptake and soil P availability. Moreover, combined applications of poultry manure, frass, and mycorrhiza recorded higher P values than sole amendments, reflecting nutrient synergy.

The residual effect of the soils shows lower concentration of sodium potassium and calcium and magnesium compared to the values gotten after application of amendments. This decline is expected since basic cations are often lost through leaching in coarse-textured soils and by uptake and removal with crop harvest

(Sharma *et al.*, 2022).

Despite these losses, treatment T12 maintained the highest residual nutrient levels, with Na at 0.14 cmol/kg, K at 0.51 cmol/kg, and Mg at 0.25 cmol/kg, indicating that poultry manure contributed significantly to the retention of exchangeable bases. Poultry manure is particularly nutrient-rich, supplying substantial amounts of K, Ca, Mg, and other macronutrients in readily available forms during mineralization (Agbede *et al.*, 2024).

Moreover, (Zhao *et al.* 2025) observed that livestock and poultry manures provide continuous nutrient release and improve cation exchange capacity, thereby enhancing nutrient availability even after harvest.

The EA ranges from the highest T4(BFF) at 1.13 cmol/kg to the lowest value T11 at 0.50 cmol/kg which indicates that (BFF) buffered soil acidity by supplying basic actions that neutralize H<sup>+</sup> and Al<sup>3+</sup> ions which is consistent with findings by (Houben *et al.*, 2022)

The ECEC control(T1) was at 1.72 cmol/kg while the highest was at T8(MY+BFF+DIG) 2.30cmol/kg The increase in ECEC from 1.72 cmol/kg (control) to 2.30 cmol/kg (T8) reflects the contribution of organic matter and microbial activity from amendments in enhancing soil colloidal surfaces and nutrient retention (Agegnehu *et al.*, 2016).

For The base saturation a significant increase was recorded in T11(MY +BFF) at 65.68% as the highest compared to the control (T1) at 41.75% recorded as the lowest this suggests that improved soil fertility due to higher exchangeable bases supplied by organic residues, aligning with reports by Adekiya *et al.*(2019).

#### **4.3 Microbial properties (bacteria) of amended soils after harvest**

**Cultural morphological and microscopic characteristics of bacterial isolates obtained from samples**

*Bacillus subtilis*, *Klebsiella oxytoca*, *Serratia marcescens*, *Staphylococcus aeruginosa*, *Micrococcus luteus*, *Enterobacter aerogenes* and *Escherichia coli*.

*Bacillus subtilis* widely documented for its role in soil health and biocontrol. It produces antimicrobial compounds like surfactin and fengycin, which suppress soil-borne pathogens, such as *Rhizoctonia* and *Fusarium spp* (Chen *et al.*, 2020).

Additionally, it improves soil structure through exopolysaccharide production and promotes root colonization, enhancing nutrient uptake and resistance to abiotic stresses.

*Klebsiella oxytoca* is a nitrogen-fixing bacterium capable of colonizing the rhizosphere. In cultivated soils, it contributes to nitrogen cycling by converting atmospheric nitrogen into forms usable by plants. It also produces IAA and siderophores, which facilitate iron uptake and root elongation (Beiranvand *et al.*, 2020).

*Serratia marcescens* is known for its antagonistic activity against fungal pathogens due to production of chitinase and protease enzymes. It enhances soil biological control potential and contributes to nutrient cycling via organic matter decomposition. Its presence in soil can improve plant resistance to diseases and reduce reliance on chemical fungicides (Mabood *et al.*, 2016).

*Staphylococcus aureus* is not typically soil-dwelling and its detection suggests contamination from animal waste like poultry manure. Although it does not contribute positively to soil health, its presence could pose risks, especially in the cultivation of edible crops. It can survive in soil for extended periods and may interfere with the microbial equilibrium (Ibekwe *et al.*, 2016)

Table 4.3. Cultural, morphological and microscopic characteristics of bacterial isolates obtained from samples

Morphological							
Elevation	Raised	Flat	Flat	Raised	Raised	Flat	Flat
Margin	smooth	Undulate	Entire	Entire	Undulate	Undulate	Undulate
Color	Cream	Cream	Cream	Cream	yellow	Cream	Cream
Shape	Irregular	Irregular	Circular	Circular	Irregular	Irregular	Irregular
Size	Small	large	Small	Medium	Small	Large	Large
Gr. diff. agar	MSA	BCA	EMB	EMB	MSA	EMB	EMB
Colour	Yellow	Straw	Pink	opaque	Pink	green	Pink
Staining							
Gram stain	+	+	-	-	+	-	-
cell type	Cocci	Rod	Rod	rod	Cocci	Rod	Rod
Arrangement	clusters	disperse	disperse	disperse	tetrads	disperse	disperse
Color	purple	purple	pink	pink	purple	pink	Pink
Spore staining	-	+	-	-	-	-	-
Biochemical							
KOH String Test	-	-	+	+	-	+	+
Catalase	+	+	+	+	+	+	+
Indole	-	-	-	-	-	+	-
Citrate	+	+	+	+	+	-	+
Oxidase	-	-	-	-	+	-	-
Motility	-	+	-	+	-	+	+
Urease	+	-	+	-	+	-	-
Glucose	+	+	+	+	-	+	+
Sucrose	+	+	+	+	-	-	+
Lactose	+	+	+	+	-	+	+
Mannitol	-	+	-	+	-	-	-
Gas formation	-	-	+	-	-	+	-
H <sub>2</sub> S formation	-	-	-	-	-	-	-
TSI (Slant/Butt) reaction	A/A*	A/A	A/AG	K/A (*A/A)	K/K*	A/AG	A/A(K*)G*
Esculin Hydrolysis	-	-	+	-	-	-	+
Identity	<i>Staphylococcus aureus</i>	<i>Bacillus subtilis</i>	<i>Klebsiella oxytoca</i>	<i>Serratia marcescens</i>	<i>Micrococcus luteus</i>	<i>Escherichia coli</i>	<i>Enterobacter aerogenes</i>

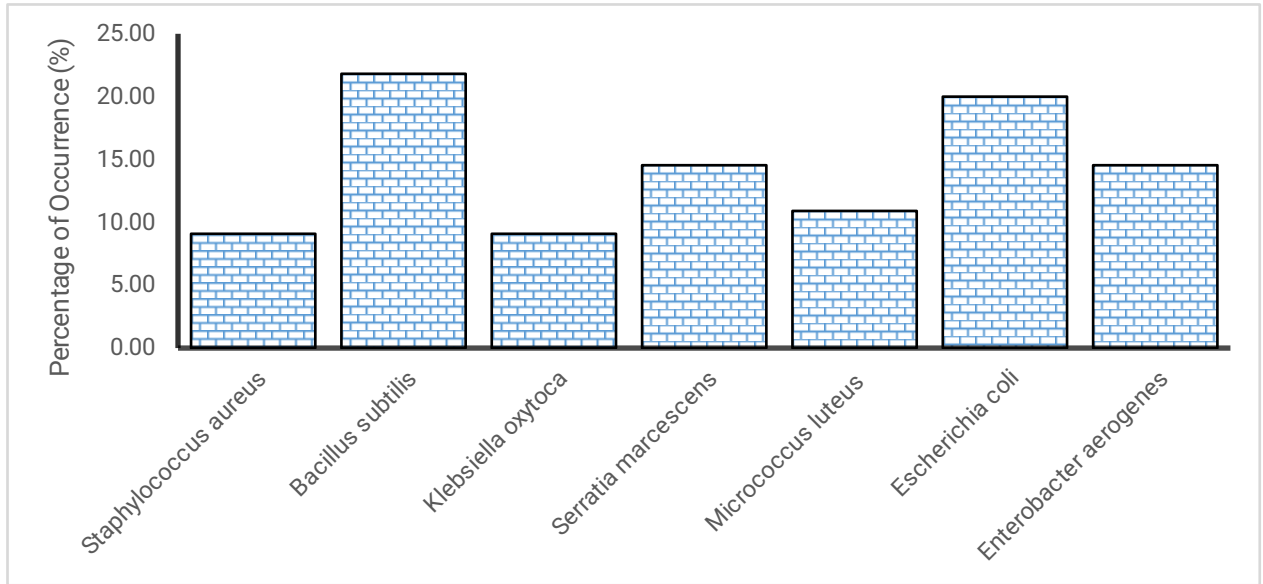


*Pseu*

Table 4.4. Plant growth-promoting properties of bacterial isolates

Isolates	Nitrogen Fixation	Ammonia Production	IAA production	Phosphate Solubilization n	PSI
<i>Staphylococcus aureus</i>	-	-	-	-	0
<i>Bacillus subtilis</i>	+	+	+	+	7
<i>Klebsiella oxytoca</i>	-	-	-	-	0
<i>Serratia marcescens</i>	+	+	-	-	0
<i>Micrococcus luteus</i>	+	+	+	+	5
<i>Escherichia coli</i>	-	-	-	-	0
<i>Enterobacter aerogenes</i>	+	+	-	+	5

Figure 4.5. Frequency of bacteria occurrence obtained from the different sample treatment



#### 4.6 Microbial properties (fungi) of the amended soil after harvest

Cultural, morphological and microscopic characteristics of fungi isolates obtained from samples

*Aspergillus Niger*, *Trichoderma sp*, *Penicillium sp*, *Rhizopus arrhizus*, *Mucor mucedo*, *Aspergillus Flavus*

##### ***Aspergillus niger***

*Aspergillus niger* plays a vital role in soil nutrient cycling by secreting large amounts of organic acids such as citric and oxalic acids, which solubilize insoluble phosphate and micronutrients, making them more available to plants. This enhances root uptake efficiency and contributes to improved crop growth. In addition, it is a strong decomposer of organic residues, facilitating organic matter turnover in amended soils. Recent findings have also highlighted its role in soil remediation, as *A. niger* strains isolated from red soils demonstrated the ability to tolerate and adsorb high concentrations of heavy metals, particularly chromium, while still contributing to nutrient cycling (Xu *et al.*, 2023). These functional roles confirm the ecological importance of *A. niger* in promoting soil fertility and sustaining plant health in organically managed systems.

##### *Trichoderma spp*

*Trichoderma species* are widely recognized as beneficial soil fungi due to their dual role as decomposers and biocontrol agents. They rapidly colonize organic substrates, producing extracellular enzymes such as cellulases and chitinases that break down plant residues, thereby releasing nutrients for plant uptake. Beyond decomposition, *Trichoderma* exerts strong antagonism against soil-borne pathogens

such as *Fusarium* and *Rhizoctonia* through mechanisms like mycoparasitism, antibiosis, and competition for space and nutrients. Moreover, they induce systemic resistance in host plants and stimulate root elongation through the production of auxin-like metabolites. Recent research confirmed that isolates of *Trichoderma harzianum* and *T. asperellum* not only suppressed soil-borne pathogens but also improved soil fertility under organic amendment. This demonstrates that *Trichoderma* contributes simultaneously to nutrient availability and plant disease management (Kose *et al.*, 2024)

Table 4.7 Cultural, morphological and microscopic characteristics of fungal isolates obtained from samples

Cultural morphology							
Colour of mycelium on agar plate	Dark colored growth	Green mycelium	Army green and entire, non-luxuriant with concentric ring	Initially white, with age turning gray and developing black dots	grey to off-white or white	wooly yellow to yellowish green to lime-green	
colour of plate culture reverse	Dark	Pale yellow	Orange	light gray	black	cream	
<b>Microscopic characteristics</b>							
Nature of hyphae	Septate	Septate	Septate	Non-septate	Non-septate	Septate	
Type of Spore	Conidiospore	Conidiospore	Conidiospore	Sporangiophores	Sporangiophores	Conidiospore	
Spore structure/Attachment	A. niger consists of a smooth and colorless conidiophores and spores.	Conidia size and shape are similar to Penicillium and Aspergillus but Trichoderma forms sticky clumps of conidia with a distinctive green pigment rather than in chains. Typical green spore clumps are identified as Trichoderma.	clear (not pigmented) hyphae with smooth-walled conidiophores, stipes are rather long and is biverticillate	single and unbranched sporangiophore	sporangiospores	yellowish-green spores on the upper surface and reddish-gold on the lower surface.	
Rhizoids	Absent	Absent	Absent	Present	Absent	Absent	
Appearance of special structure	Conidial heads radiate, becoming columnar when mature; conidiophores are long and smooth-walled; biseriate; two rows of phialides cover the entire vesicle.	Conidiophores hyaline and loosely branched at right angles. Phialides flask-shaped and inflated at the base, with very short collarettes	Conidiophore stipes smooth-walled; phialides mono- or biverticillate, flask-shaped. Phialides do not show long pointed extensions at the tips	Rhizoids occur at the junction of stolon and sporangiophore	sporangia are produced on the tips of sporangiophores. The sporangia contain spores, which are the reproductive units of Mucor	Conidial heads radiate; uniseriate and biseriate; rough-walled stipe (inset); smooth-walled to rough-walled conidia.	

<b>Class of fungi</b>	Ascomycetes	Ascomycetes	Ascomycetes	Zygomycetes	Zygomycetes	Ascomycete
<b>Possible Identity</b>	<i>Aspergillus niger</i>	<i>Trichoderma</i> sp.	<i>Penicillium</i> sp.	<i>Rhizopus arrhizus</i>	<i>Mucor mucedo</i>	<sup>S</sup> <i>Aspergillus flavus</i>
<hr/>						
	<i>Penicillium spp</i>					

#### 4.8 Frequency of fungal occurrence obtained from different sample of treatment

The percentage occurrence of various fungal species isolated from organically treated samples are presented in figure 4.8.1

*Aspergillus niger* recorded the highest frequency at 23.47%, indicating its dominant and widespread presence across treatments. This aligns with the findings of Gautam *et al.* (2011), who emphasized its strong ability to degrade complex organic substrates and its adaptability to diverse organic environments. *Trichoderma* sp. and *Aspergillus flavus*, each with a frequency of 20.28%, reflect their competitive colonization potential in nutrient-rich soils; *Trichoderma*, in particular, is recognized for its plant growth promoting and biocontrol functions (Harman *et al.*, 2019), while *Aspergillus flavus* has been frequently isolated from composts and organic environments, highlighting its tolerance for biologically active soils (Kumar *et al.*, 2015). *Rhizopus arrhizus* also showed a notable presence (15.50%), reflecting its efficiency in decomposing organic matter and contributing to nutrient mineralization in amended soils (Al-Hatmi *et al.*, 2019).

#### 4.9 Plant growth promoting properties of fungi isolates

##### *Trichoderma* sp.

This isolate tested positive (+) for both nitrogen fixation and phosphate solubilization, with a PSI value of 4, showing strong plant growth-promoting potential. *Trichoderma* species are widely reported to solubilize phosphate and produce secondary metabolites that enhance root growth and nutrient uptake (Soares *et al.*, 2020). Their presence in your soil suggests they can improve phosphorus availability and possibly contribute to nitrogen cycling, enhancing plant nutrition and soil fertility.

##### *Penicillium* sp.

The results showed absence (–) of nitrogen fixation and phosphate solubilization. While many *Penicillium* strains are known phosphate solubilizers, producing gluconic acid and phosphatases (Rodrigues *et al.*, 2022), your isolate did not show these traits. This suggests that the strain present in your soil may not have expressed the necessary metabolic pathways under the tested conditions, limiting its role in plant growth promotion.

#### *Rhizopus arrhizus*

This isolate was positive (+) for nitrogen fixation but negative (–) for phosphate solubilization. Although *Rhizopus* is not commonly recognized as a diazotroph, some isolates may harbor nitrogen-fixing potential under specific conditions (Ali *et al.*, 2023). The absence of phosphate solubilization limits its contribution to phosphorus nutrition, but its nitrogen-fixing trait could support plant nitrogen demand.

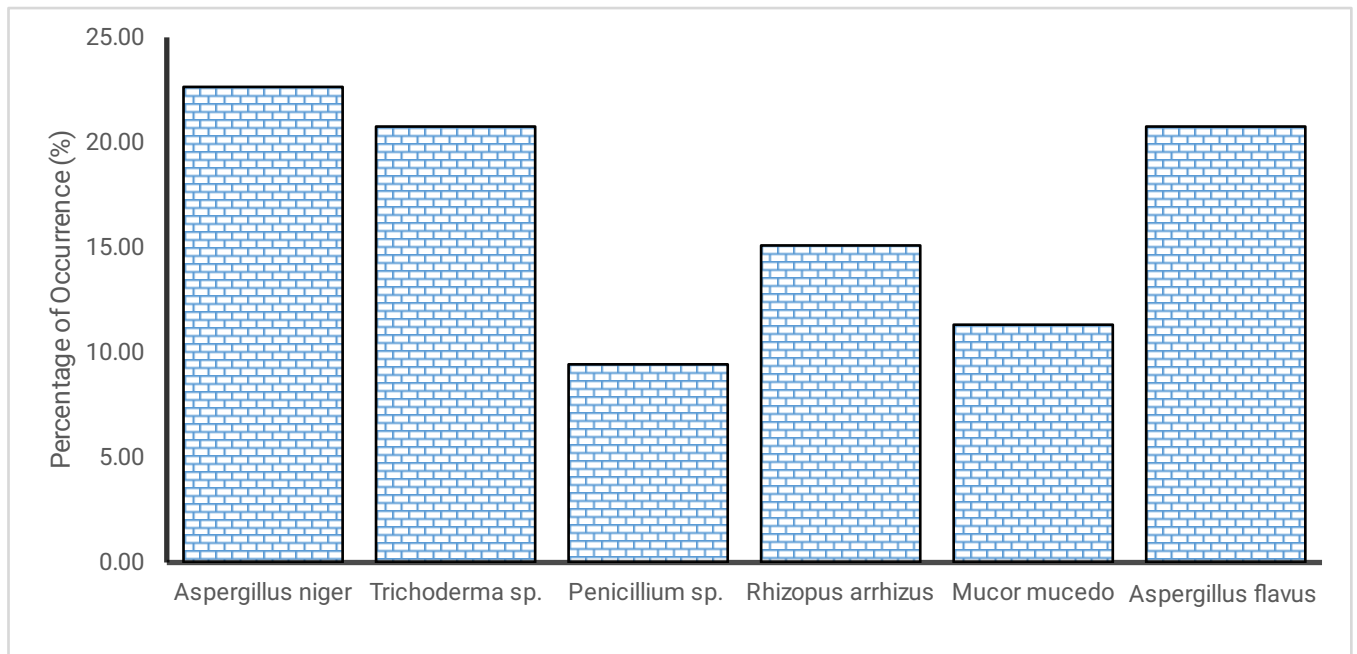
#### *Mucor mucedo*

Your isolate showed absence (–) for both traits. *Mucor* species are not typically reported as significant contributors to phosphorus solubilization or nitrogen fixation (Sharma *et al.*, 2021). Thus, their role in plant growth promotion in your soil appears minimal.

#### *Aspergillus flavus*

This isolate was negative (–) for both nitrogen fixation and phosphate solubilization in your test. However, some studies report *A. flavus* strains as phosphate solubilizers capable of releasing P from insoluble forms (Li *et al.*, 2024).

**Figure 4.8.1 Frequency of Fungi occurrence obtained from the different sample treatment**



**Table 4.9.1. Plant growth-promoting properties of fungi isolates**

Isolates	Nitrogen Fixation	Phosphate Solubilization	PSI
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<i>Aspergillus niger</i>	-	-	0
<i>Trichoderma sp.</i>	+	+	4
<i>Penicillium sp.</i>	-	-	0
<i>Rhizopus arrhizus</i>	+	-	0
<i>Mucor mucedo</i>	-	-	0
<i>Aspergillus flavus</i>	-	-	0

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#### **4.9.2 Heterotrophic bacteria counts of treatment in year 2024 Vs 2025**

The heterotrophic bacteria counts in 2024 vs 2025 for the treatments show different trends compared to fungi .

Control (T1) shows an increase from 5.20 in 2024 to 5.27 in 2025

The highest bacterial count is seen in T10 and T11 treatments in 2025, where values reached 5.74 compared to 5.47 and 5.45 respectively in 2024

The increase in bacterial counts, particularly in amended soils, suggests enhanced bacterial growth or activity possibly due to sustained or increasing substrate availability or changing environmental conditions favorable to bacteria

Unlike fungi, bacteria may respond positively over a longer time as they can utilize more varied substrates and adapt dynamically to changes in soil conditions, which can explain their increasing counts in 2025 despite declines in fungal counts.

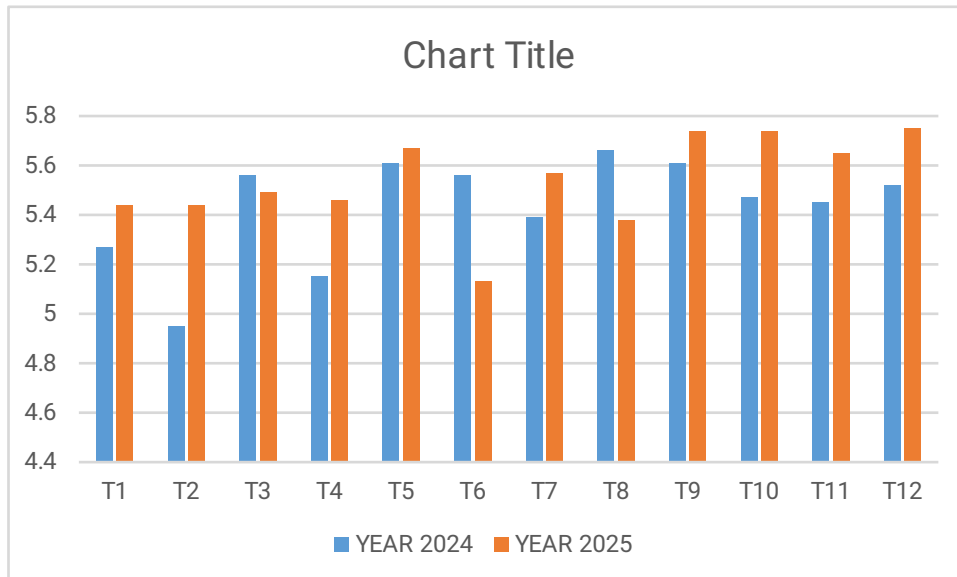
Studies indicate that bacterial populations can benefit from organic amendments over prolonged periods as bacterial community composition shifts towards those capable of degrading more recalcitrant organic matter. The modest increase in the control also indicates natural bacterial growth in soil independent of amendments but is enhanced in treated soils due to better nutrient and substrate availability.

#### **4.9.4 Heterotrophic fungi counts of different treatments in year 2024 Vs 2025**

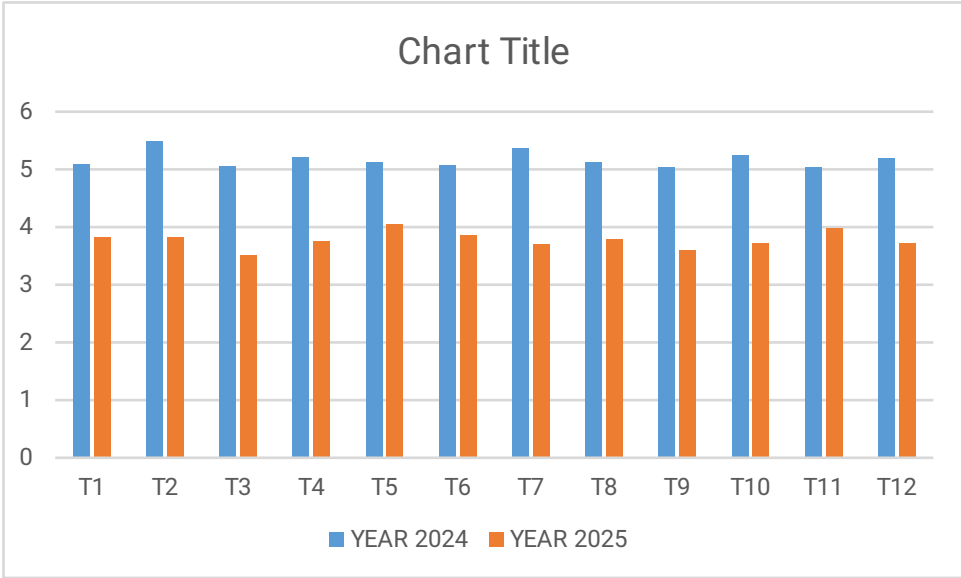
Across all treatments (T1 to T12), soil heterotrophic fungi counts were greater in 2024 than in the corresponding treatments in 2025. This suggests a general decline in these microbial populations over the observed period, which could be attributed to factors such as nutrient depletion, environmental changes, or the residual effects of previous organic amendments. Control (T1) registered a heterotrophic fungi count of 5.09 in 2024, which decreased to 3.83 in 2025. The highest value was observed in Treatment 2 (poultry manure) with 5.49 in 2024, declining to 3.82 in 2025. The

difference between T1 (control) and T2 (highest) in 2024 is notable, suggesting enhanced microbial activity due to the amendment in T2. However, by 2025, the gap was reduced, possibly due to the diminishing residual effects of the treatment. Lower counts in 2025 may reflect reduced organic substrate availability after the initial amendment effects peak. This trend aligns with reports by Nguyen *et al.* (2023), who observed that heterotrophic fungi populations increase shortly after organic material incorporation but decline over time as available carbon sources become depleted.

**Figure 4.9.3 Soil Heterotrophic Bacteria count in year 2025 vs 2024**



**Figure 4.9.5 Soil Heterotrophic fungi count in year 2024 vs 2025**



#### 4.9.6 Heterotrophic Bacterial Counts

Heterotrophic bacterial counts of the treatments are presented in Figure 2. Based on the table, the bacterial counts (Log<sub>10</sub> cfu/g) across treatments showed close but numerically different values, although the differences were not statistically significant. This outcome suggests that while organic amendments and microbial inoculants contribute to bacterial proliferation, their effect on heterotrophic bacterial populations may be more stabilizing than disruptive, maintaining overall balance in umicrobial communities. Similar observations were reported by (Agegnehu *et al.* (2016), who noted that organic inputs improved microbial abundance but often without significant statistical differences due to natural soil variability.

#### 4.9.7 Heterotrophic Fungal Counts

Heterotrophic fungal counts (T1–T12) varied significantly ( $p \leq 0.05$ ) across treatments, showing that the type of organic amendment applied strongly influenced microbial activity. T5 (digestate) has the highest fungal count ( $5.04 \times 10^5$  cfu/g), significantly higher than other treatments, indicating that digestate enriched fungal populations through its readily available carbon and nutrients, consistent with Sánchez-Monedero *et al.* (2018). In contrast, T6 (sole mycorrhiza) had the lowest fungal population, significantly different from the amended treatments, likely due to the competitive dominance of mycorrhizal fungi and limited substrate availability, as reported by Berruti *et al.* (2016). Overall, treatments with organic inputs supported higher fungal counts than the control, highlighting the importance of amendment type in sustaining microbial communities.

Residual effect on soil bacterial and fungi population

Treatments	Bacterial Population (Cfu g <sup>-1</sup> )	Fungal Population (Cfu g <sup>-1</sup> )
T1	5,44 <sup>ab</sup>	3.83 <sup>abcd</sup>
T2	5,44 <sup>ab</sup>	3.82 <sup>abcd</sup>
T3	5.49 <sup>ab</sup>	3.51 <sup>d</sup>
T4	5.46 <sup>ab</sup>	3.76 <sup>abcd</sup>
T5	5.67 <sup>a</sup>	4.04 <sup>a</sup>
T6	5.13 <sup>b</sup>	3.86 <sup>abc</sup>
T7	5.57 <sup>ab</sup>	3.70 <sup>bcd</sup>
T8	5.38 <sup>ab</sup>	3.79 <sup>abcd</sup>
T9	5.74 <sup>a</sup>	3.60 <sup>cd</sup>
T10	5.74 <sup>a</sup>	3.71 <sup>bcd</sup>
T11	5.65 <sup>a</sup>	3.98 <sup>ab</sup>
T12	5.75 <sup>a</sup>	3.72 <sup>abcd</sup>

## Comparison of the physical chemical properties of the treatments in 2024 VS 2025

The physical and chemical properties of the soil under Treatments 2–12 for 2024 and 2025 revealed notable variations influenced by the type and combination of organic amendments applied. Overall, soil reaction (pH) declined slightly across most treatments, indicating a gradual shift toward acidity. For instance, pH decreased in Treatment 3 (Mycorrhiza) from 6.47 to 6.00 and in Treatment 5 (Digestate) from 6.43 to 5.63. This acidification trend may be attributed to leaching of basic cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{K}^+$ ), crop uptake, and organic acid release during decomposition, as reported by Ogunlade *et al.* (2020). While organic materials generally buffer soil pH (Chen *et al.*, 2023), the observed decline suggests the predominance of acid-forming residues and limited soil buffering capacity.

Organic carbon (OC) and organic matter (OM) contents increased substantially from 2024 to 2025 across most treatments, reflecting the residual impact of organic amendments. The highest organic carbon increase occurred in Treatment 12 (Digestate + Poultry Manure), from 3.10 to 20.10 Ns/cm, while OM rose from 5.30 to 34.60 g/kg. These increases signify sustained decomposition, humus formation, and improved carbon sequestration potential, consistent with findings by Zhao *et al.* (2021) and Kätterer *et al.* (2019). Enhanced OC and OM levels indicate better soil structure, water retention, and fertility restoration, aligning with earlier observations by Abioye *et al.* (2020) and Ogunwole *et al.* (2019) that organic residues promote long-term soil productivity through humification.

Conversely, total nitrogen (TN) levels declined slightly in several treatments—for example, from 0.30 to 0.13 g/kg in Treatment 7 (PM + MY + BFF) and from 0.28 to 0.18 g/kg in Treatment 12 (DIG + PM). This reduction likely resulted from plant

uptake, leaching, or temporary immobilization of nitrogen into stable organic compounds, as noted by Okebalama *et al.* (2019). Despite the decline, the concurrent rise in organic matter suggests future nitrogen replenishment through gradual mineralization. Available phosphorus (P) also decreased, particularly in Treatment 4, from 4.99 to 1.10 mg/kg, due to plant absorption and P fixation by Fe and Al oxides under acidic conditions (Akinrinde *et al.*, 2019)

Exchangeable potassium ( $K^+$ ) levels declined moderately between years (e.g., from 2.87 to 1.43 cmol/kg in Treatment 10, BFF + DIG), likely due to crop removal and leaching. However, organic matter presence helped buffer excessive losses by enhancing cation exchange capacity, as observed by Fan *et al.* (2020). Exchangeable calcium ( $Ca^{2+}$ ) and magnesium ( $Mg^{2+}$ ) generally increased in some treatments, such as Treatment 6, where  $Ca^{2+}$  rose from 0.18 to 0.33 cmol/kg and  $Mg^{2+}$  from 0.09 to 0.21 cmol/kg, attributed to nutrient release from decomposing residues (Abioye *et al.*, 2020). These cations contribute to improved soil structure and nutrient balance (Ogunwole *et al.*, 2019). Exchangeable sodium ( $Na^+$ ) showed minor increases but remained within non-saline limits, indicating no structural hazard and aligning with observations by Liu *et al.* (2023).

Exchangeable acidity (EA) increased in most treatments, such as T2, from 0.30 to 0.70 cmol/kg, reflecting the decline in base saturation and buildup of acid ions, as supported by Ukaegbu *et al.* (2022). However, mixed amendments like MY + BFF + DIG mitigated acidity through cation release and organic buffering (Fan *et al.*, 2020). Soil textural fractions (sand, silt, and clay) showed minimal variation across years, reaffirming that soil texture is relatively stable and governed by parent material. Slight increases in silt and clay may result from organic matter-induced aggregation, which improves porosity and structure (Ogunwole *et al.*, 2019)

Overall, the results demonstrate that organic amendments significantly improved soil carbon, organic matter, and base cation levels, while moderate declines in pH, nitrogen, and phosphorus indicate ongoing nutrient cycling and the need for continuous organic input. The residual effects observed in 2025 confirm the potential of combined organic materials to sustain soil fertility and enhance long-term soil health under tropical conditions.

## THE COMPARISON OF THE PHYSICAL AND CHEMICAL PROPERTIES OF TREATMENTS IN 2024 VS 2025

		P H (1:1)	O.C Ns/cm	O.M g/kg	T.N g/kg	AV.P Mg/kg	K Cmol/kg	Ca	Mg	Na Cmol/kg	EA Cmol/kg	Sand g/kg	Silt g/kg	Clay g/kg
T1	CONTRPOL													
T2	2024	6.40 <sup>A</sup>	3.90 <sup>b</sup>	6.70 <sup>b</sup>	0.35 <sup>a</sup>	5.33 <sup>a</sup>	0.93 <sup>a</sup>	0.57 <sup>a</sup>	0.33 <sup>a</sup>	0.19 <sup>a</sup>	0.30 <sup>b</sup>	848.0 <sup>a</sup>	9.00 <sup>a</sup>	143.00 <sup>a</sup>
	2025	6.00 <sup>b</sup>	14.55 <sup>a</sup>	25.43 <sup>a</sup>	0.13 <sup>b</sup>	1.32 <sup>b</sup>	0.20 <sup>b</sup>	0.15 <sup>b</sup>	0.10 <sup>b</sup>	0.05 <sup>b</sup>	0.70 <sup>a</sup>	872.0 <sup>a</sup>	8.00 <sup>b</sup>	120.00 <sup>b</sup>
T3	2024	6.47 <sup>a</sup>	1.00 <sup>b</sup>	1.70 <sup>b</sup>	0.09 <sup>b</sup>	2.60 <sup>a</sup>	0.37 <sup>b</sup>	0.15 <sup>b</sup>	0.07 <sup>b</sup>	0.03 <sup>b</sup>	0.40 <sup>b</sup>	886.0 <sup>a</sup>	3.00 <sup>b</sup>	111.0 <sup>b</sup>
	2025	6.00 <sup>b</sup>	17.37 <sup>a</sup>	29.93 <sup>a</sup>	0.16 <sup>a</sup>	1.71 <sup>b</sup>	0.41 <sup>a</sup>	0.30 <sup>a</sup>	0.20 <sup>a</sup>	0.11 <sup>a</sup>	0.63 <sup>a</sup>	866.0 <sup>b</sup>	11.00 <sup>a</sup>	123.0 <sup>a</sup>
T4	2024	6.23 <sup>a</sup>	3.50 <sup>b</sup>	6.00 <sup>b</sup>	0.32 <sup>a</sup>	4.99 <sup>a</sup>	0.88 <sup>a</sup>	0.51 <sup>a</sup>	0.28 <sup>a</sup>	0.15 <sup>a</sup>	0.40 <sup>b</sup>	853.0 <sup>b</sup>	7.00 <sup>b</sup>	140.00 <sup>a</sup>
	2025	5.70 <sup>b</sup>	14.00 <sup>a</sup>	24.10 <sup>a</sup>	0.13 <sup>b</sup>	1.10 <sup>b</sup>	0.22 <sup>b</sup>	0.15 <sup>b</sup>	0.11 <sup>b</sup>	0.06 <sup>b</sup>	1.13 <sup>a</sup>	873.0 <sup>a</sup>	8.00 <sup>a</sup>	119.00 <sup>b</sup>
T5	2024	6.43 <sup>a</sup>	2.60 <sup>b</sup>	4.50 <sup>b</sup>	0.24 <sup>a</sup>	3.80 <sup>a</sup>	0.75 <sup>a</sup>	0.30 <sup>b</sup>	0.16 <sup>b</sup>	0.09 <sup>b</sup>	0.40 <sup>b</sup>	872.0 <sup>a</sup>	4.00 <sup>B</sup>	124.0 <sup>a</sup>
	2025	5.63 <sup>b</sup>	16.20 <sup>a</sup>	27.90 <sup>a</sup>	0.15 <sup>b</sup>	1.63 <sup>b</sup>	0.40 <sup>b</sup>	0.32 <sup>a</sup>	0.20 <sup>a</sup>	0.11 <sup>a</sup>	1.10 <sup>a</sup>	872.0 <sup>a</sup>	7.00 <sup>a</sup>	135.0 <sup>b</sup>
T6	2024	6.10 <sup>A</sup>	2.00 <sup>b</sup>	3.40 <sup>b</sup>	0.18 <sup>a</sup>	3.10 <sup>a</sup>	0.50 <sup>a</sup>	0.18 <sup>b</sup>	0.09 <sup>b</sup>	0.06 <sup>b</sup>	0.30 <sup>b</sup>	884.0 <sup>a</sup>	3.00 <sup>a</sup>	119.0 <sup>b</sup>
	2025	5.70 <sup>b</sup>	17.80 <sup>a</sup>	30.60 <sup>b</sup>	0.16 <sup>b</sup>	1.84 <sup>b</sup>	0.44 <sup>b</sup>	0.33 <sup>a</sup>	0.21 <sup>a</sup>	0.12 <sup>a</sup>	1.00 <sup>a</sup>	868.0 <sup>b</sup>	3.00 <sup>a</sup>	124.0 <sup>a</sup>
T7	2024	6.23 <sup>a</sup>	3.30 <sup>b</sup>	5.70 <sup>b</sup>	0.30 <sup>a</sup>	4.77 <sup>a</sup>	0.83 <sup>a</sup>	0.46 <sup>a</sup>	0.25 <sup>a</sup>	0.13 <sup>a</sup>	0.40 <sup>b</sup>	858.0 <sup>b</sup>	7.00 <sup>b</sup>	121.0 <sup>a</sup>
	2025	5.80 <sup>b</sup>	14.10 <sup>a</sup>	24.30 <sup>a</sup>	10.13 <sup>b</sup>	1.17 <sup>b</sup>	0.25 <sup>b</sup>	0.19 <sup>b</sup>	0.12 <sup>b</sup>	0.07 <sup>b</sup>	1.00 <sup>a</sup>	870.0 <sup>a</sup>	11.00 <sup>a</sup>	113.0 <sup>b</sup>
T8	2024	6.20 <sup>a</sup>	2.30 <sup>b</sup>	4.00 <sup>b</sup>	0.21 <sup>a</sup>	13.50 <sup>a</sup>	0.71 <sup>a</sup>	0.24 <sup>a</sup>	0.14 <sup>a</sup>	0.08 <sup>a</sup>	0.13 <sup>a</sup>	876.0 <sup>a</sup>	3.00 <sup>b</sup>	121.0 <sup>a</sup>
	2025	6.00 <sup>b</sup>	13.30 <sup>a</sup>	22.90 <sup>a</sup>	0.12 <sup>b</sup>	11.90 <sup>b</sup>	0.21 <sup>b</sup>	0.16 <sup>a</sup>	0.10 <sup>a</sup>	0.06 <sup>b</sup>	0.07 <sup>b</sup>	872.0 <sup>b</sup>	10.00 <sup>a</sup>	118.0 <sup>b</sup>
T9	2024	6.33 <sup>a</sup>	2.70 <sup>b</sup>	4.60 <sup>b</sup>	0.25 <sup>a</sup>	4.45 <sup>a</sup>	0.79 <sup>a</sup>	0.35 <sup>a</sup>	0.19 <sup>b</sup>	0.11 <sup>b</sup>	0.40 <sup>a</sup>	867.0 <sup>a</sup>	5.00 <sup>a</sup>	128.0 <sup>a</sup>
	2025	5.70 <sup>b</sup>	19.87 <sup>a</sup>	34.23 <sup>a</sup>	0.18 <sup>b</sup>	2.10 <sup>b</sup>	0.48 <sup>b</sup>	0.36 <sup>a</sup>	0.23 <sup>a</sup>	0.13 <sup>a</sup>	1.10 <sup>b</sup>	863.0 <sup>a</sup>	11.00 <sup>a</sup>	126.0 <sup>b</sup>
T10	2024	6.10 <sup>a</sup>	1.50 <sup>a</sup>	2.60 <sup>b</sup>	0.14 <sup>a</sup>	0.50 <sup>b</sup>	2.87 <sup>a</sup>	0.17 <sup>a</sup>	0.08 <sup>a</sup>	0.05 <sup>b</sup>	0.50 <sup>a</sup>	885.0 <sup>a</sup>	3.00 <sup>b</sup>	112.0 <sup>b</sup>
	2025	5.90 <sup>b</sup>	10.40 <sup>a</sup>	26.30 <sup>a</sup>	0.14 <sup>a</sup>	1.00 <sup>a</sup>	1.43 <sup>b</sup>	0.24 <sup>a</sup>	0.16 <sup>a</sup>	0.09 <sup>a</sup>	1.00 <sup>a</sup>	872.0 <sup>b</sup>	8.00 <sup>a</sup>	120.0 <sup>a</sup>
T11	2024	6.43 <sup>a</sup>	2.00 <sup>b</sup>	3.40 <sup>b</sup>	0.19 <sup>a</sup>	3.22 <sup>a</sup>	0.53 <sup>a</sup>	0.20 <sup>b</sup>	0.11 <sup>a</sup>	0.07 <sup>a</sup>	0.40 <sup>a</sup>	880.0 <sup>a</sup>	3.00 <sup>b</sup>	117.0 <sup>a</sup>
	2025	6.01 <sup>b</sup>	16.00 <sup>a</sup>	27.50 <sup>a</sup>	0.15 <sup>a</sup>	1.51 <sup>b</sup>	0.39 <sup>b</sup>	0.28 <sup>a</sup>	0.19 <sup>a</sup>	0.10 <sup>a</sup>	0.50 <sup>a</sup>	873.0 <sup>b</sup>	7.00 <sup>a</sup>	120.0 <sup>a</sup>
T12	2024	6.20 <sup>a</sup>	3.10 <sup>b</sup>	5.30 <sup>b</sup>	0.28 <sup>a</sup>	4.61 <sup>a</sup>	0.80 <sup>a</sup>	0.42 <sup>a</sup>	0.21 <sup>a</sup>	0.83 <sup>a</sup>	0.30 <sup>b</sup>	864.0 <sup>a</sup>	5.00 <sup>b</sup>	131.0 <sup>a</sup>
	2025	5.91 <sup>b</sup>	20.10 <sup>a</sup>	34.60 <sup>a</sup>	0.18 <sup>b</sup>	2.14 <sup>b</sup>	0.51 <sup>b</sup>	0.38 <sup>a</sup>	0.25 <sup>a</sup>	0.25 <sup>a</sup>	1.00 <sup>a</sup>	863.0 <sup>a</sup>	8.00 <sup>a</sup>	129.0 <sup>a</sup>

**KEYWORD: electrical conductivity(EC), organic carbon(OC), total nitrogen(TN), available phosphorus(P), exchangeable potassium(K), exchangeable calcium(Ca), exchangeable magnesium(Mg), exchangeable sodium(Na), exchangeable acidity(EA), cation exchange capacity(CEC), base saturation(BS).**

## CHAPTER FIVE

### 5.0 CONCLUSION AND RECOMMENDATION

#### 5.1 CONCLUSION

The study demonstrated that the residual effects of organic amendments particularly combinations such as mycorrhiza, black soldier fly frass, and digestate positively influenced the physical, chemical, and microbial properties of soils previously cultivated with bell pepper (*Capsicum annuum L.*). Although some nutrient levels slightly declined compared to the initial season, amended soils maintained superior fertility, better structure, and enhanced biological activity than the untreated control. The persistence of beneficial microbial communities, including *Aspergillus*, *Trichoderma*, and *Klebsiella* species, reflects improved soil ecological balance and nutrient cycling. Overall, the results confirm that organic amendments not only and health across cropping seasons.

#### 5.2 Recommendations

Based on this findings the following recommendations were made :

1. Use of Combined Amendments: Integrated applications of organic materials (e.g., mycorrhiza + digestate + black soldier fly frass) should be encouraged, as they produce synergistic and more durable improvements in soil fertility.
2. Long-Term Monitoring: Future research should track residual effects over multiple cropping cycles to determine the longevity of nutrient availability and microbial activity.
3. Soil Management Practices: Farmers should prioritize organic-based soil fertility management to reduce dependency on chemical fertilizers and promote sustainable soil restoration.

4. Microbial Enhancement: Encouraging the use of beneficial microbial inoculants, such as mycorrhizal fungi or biofertilizers, alongside organic residues can further strengthen soil plant microbe interactions for sustainable vegetable production

