

KYAMBOGO UNIVERSITY

**POTENTIAL OF USING INDIGENOUS MICROORGANISMS FOR
DECOMPOSING COFFEE AND RICE CROP WASTE INTO BIO-
FERTILIZER**

BY

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DECLARATION

I hereby declare that this is entirely my own work and it has not been submitted to any other university or institution for any award.

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APPROVAL

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DEDICATION

This work is dedicated to my late grandfather Mr. Keiriza Urabano, my husband Mr. Gatre Patrick and my children (Letasi, Clare and Owen)

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LIST OF ACRONYMS

FAO:	Food and Agriculture Organisation
IMO:	Indigenous Micro-Organism
UCDA:	Uganda Coffee Development Authority
C/N:	Carbon to Nitrogen ratio
N:	Nitrogen
P:	Phosphorus
K:	Potassium
Ca:	Calcium
Mg:	Magnesium
pH:	Quantity of hydrogen ions present in solution

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ABSTRACT

Agricultural waste contributes approximately 140 billion tonnes to global waste annually, much of it rich in nutrients originally absorbed from the soil. Managing this waste sustainably while replenishing soil fertility is critical for long-term agricultural productivity. In Uganda, coffee and rice husks are abundant crop residues but decompose slowly due to their high lignin and cellulose content. This study aimed to evaluate the effectiveness of Indigenous Microorganisms (IMOs) in accelerating the decomposition of coffee and rice husks and improving compost quality. The experiment was conducted at Kyambogo University Farm, Central Uganda, using a Completely Randomized Design (CRD) with four treatment combinations replicated five times. The treatments were;

- i) Coffee husks + goat manure (CH+GM),
- ii) Coffee husks + goat manure + IMOs (CH+GM+IMO),
- iii) Rice husks + goat manure (RH+GM), and
- iv) Rice husks + goat manure + IMOs (RH+GM+IMO).

Each composting pit contained 25 kg of material mixed at a ratio of 1:0.5 (husks to goat manure) on a dry-weight basis. A culture of beneficial anaerobic and aerobic microorganisms was prepared from leaf litter collected from a forested area adjacent to Kyambogo University Farm so as to ensure the microbes originated from a natural (indigenous) soil ecosystem conducive for microbial diversity and proliferation. Treatments with IMOs received 1 liter of IMO solution, while controls received plain water. Data on temperature, pH, moisture content, organic matter, macronutrients (N, P, K, Ca, Mg), micronutrients, and C/N ratio were collected over a 12-week composting period.

Results showed that compost temperatures ranged between 30°C and 51°C, confirming an active thermophilic phase. The CH+GM+IMO and RH+GM+IMO treatments exhibited a faster decline in the C/N ratio and significantly ($p < 0.05$) higher nutrient content and organic matter compared to non-IMO treatments. Physically, IMO-treated composts had a darker color, finer texture, and earthy odor, indicating higher maturity and stability. The enhancement by IMOs was attributed to their rich consortia of beneficial microorganisms that promoted lignin degradation and nutrient mineralization. This study indicates that use of locally adapted microbes (IMOs) significantly improved composting efficiency and nutrient recovery, demonstrating their potential as a low-cost, sustainable technology for managing coffee and rice husk wastes and producing high-quality biofertilizer in Uganda.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Agricultural production generates approximately 140 billion tons of waste globally each year (UNEP, 2009), much of which contains valuable nutrients originally absorbed from the soil. Among the major contributors to this waste are coffee (*Coffea arabica* and *Coffea canephora*) and rice (*Oryza sativa*), two of the most widely cultivated crops worldwide. Africa ranks as the third-largest producer of coffee, following Asia (28.1%) and the Americas (57.1%), while in rice production, Asia leads with 90.5%, followed by the Americas (5.2%) and Africa (6.1%) (FAO, 2023). Uganda alone produces approximately 374,760 tons of coffee and 730,000 tons of rice annually (Knoema, 2023).

Coffee and rice are central to Uganda's socio-economic development. Coffee is the country's leading export commodity, cultivated on 353,907 hectares by over 1.7 million producers and contributing about USD 485 million annually (MAAIF, 2021; Sandoz, 2013). Rice, although more recent in adoption, is increasingly significant for both food security and income generation. Under the National Rice Development Strategy, production has expanded by over 40% in the last decade, reducing imports and improving household incomes (MAAIF, 2020). Both crops therefore play a dual role: sustaining livelihoods and contributing to national economic growth, while simultaneously generating substantial agro-industrial waste.

Traditionally, Ugandan farmers relied mainly on organic sources such as animal manure, crop residues, and fallowing to maintain soil fertility, with the use of

chemical fertilizers being almost negligible (Ali et al., 2018; MAAIF, 2016). However, the intensification of rice and coffee cultivation over the past two decades has led to a noticeable increase in fertilizer use as farmers attempt to boost yields and meet market demand. For instance, in rice production, nitrogen application now ranges between 40–80 kg N/ha and phosphorus between 20–40 kg P₂O₅/ha (Balasubramanian et al., 2007; MAAIF, 2020), while coffee farmers increasingly apply 100–250 kg NPK/ha depending on affordability and access (Byekwaso et al., 2022). This represents a marked departure from past practices where fertilizer inputs were minimal.

Although average national fertilizer consumption remains among the lowest globally about 1–2 kg/ha compared to 9 kg/ha for Sub-Saharan Africa and over 100 kg/ha worldwide (FAOSTAT, 2021). This rising trend in chemical fertilizer use among coffee and rice farmers reflects a shift towards input-intensive production systems. The growing reliance on chemical fertilizers, while improving short-term yields, is increasingly linked to soil acidification, groundwater contamination, nutrient imbalances, and declining soil organic matter content (Bayabayi et al., 2022). In Uganda's tropical environment, where heavy rainfall exacerbates nutrient leaching, this trend poses long-term risks to soil fertility and sustainability.

Coffee and rice husks contribute significantly to agricultural waste. Globally, coffee husks account for about 9 million tons annually, while rice husks exceed 150 million tons (Scarlat et al., 2015). In Uganda, coffee generates approximately 1,000–1,200 kg husks per hectare (Heuzé & Tran, 2015; UCDA, 2023), while rice produces about 1,120 kg husks/ha (Hong et al., 2021; Rice Knowledge Bank, 2023). Aggregated nationally, this translates to nearly

374,000–450,000 tons of coffee husks and 820,000 tons of rice husks each year. This represents a major proportion of agricultural residues, which, if left unmanaged, contribute to pollution, greenhouse gas emissions, and nutrient depletion.

Yet, both coffee and rice husks are rich in organic matter and nutrients. Coffee husks provide 1.2–2.2% nitrogen, 0.3–0.5% phosphorus, 1.0–2.0% potassium, and high organic carbon (Kumar & Gopal, 2015; Heuzé & Tran, 2015). Rice husks contain 0.3–0.5% nitrogen, 0.1–0.2% phosphorus, 0.2–0.4% potassium, and up to 20% silica, which enhances plant resistance to pests and diseases (Juliano, 1985; Hong et al., 2021). Their effective utilization could reduce fertilizer dependence, restore soil organic matter, and promote sustainable nutrient cycling. Neglecting them means foregoing a renewable source of nutrients vital for long-term productivity.

Conventional composting offers a pathway for recycling these residues, but the high lignin, cellulose, and silica contents make them resistant to microbial breakdown, slowing decomposition and lowering nutrient release efficiency (Kumar & Gopal, 2015). In resource-limited farming systems, the lack of nitrogen-rich supplements like animal manure further reduces composting efficiency (Joshi et al., 2019).

Recent advances highlight the potential of indigenous microorganisms (IMOs) to enhance the decomposition of fibrous agricultural wastes. IMOs are locally adapted bacteria and fungi that accelerate organic matter breakdown, enhance nutrient retention, and improve compost quality (Zhang et al., 2011; Rastogi et al., 2020). Evidence shows their effectiveness: Xu et al. (2016) reported a 30–

40% reduction in composting time and greater nitrogen retention when IMO were applied to rice husks; Kim et al. (2017) observed accelerated lignin degradation in coffee husks, producing compost with higher nutrient and microbial biomass content. Such findings demonstrate that IMOs can address the limitations of traditional composting, offering an efficient and sustainable solution for managing fibrous residues.

In Uganda, where monocropping and soil nutrient depletion remain major challenges (Cabrera & Zuaznabar, 2010; Belete & Yadete, 2023), harnessing IMOs to convert coffee and rice husks into biofertilizers offers a practical opportunity. By accelerating decomposition, improving nutrient recovery, and producing stable organic fertilizers, this approach can restore soil fertility, reduce dependence on costly chemical inputs, and contribute to sustainable agricultural productivity.

This study therefore investigates the potential of using indigenous microorganisms for decomposing coffee and rice crop waste into bio-fertilizer, specifically focusing on decomposition rates, nutrient quality of the resulting biofertilizer, and the influence of IMOs on composting parameters such as pH, temperature, and macronutrient content.

1.2 Problem Statement

Uganda's increasing production of coffee and rice generates large volumes of husks as by-products. For example, coffee processing alone produces an estimated 46.6 million tons of husks annually, with individual hullers generating up to 2 tons of husk per day during peak seasons (World Bank, 1984; UNCS&T, 2013). While rice husks are partly utilized in poultry bedding and coffee husks in livestock feeding or energy production, a considerable fraction remains underutilized or inappropriately disposed of especially in rural or remote areas due to limited markets and high transport costs (SCIRP, 2019). This contributes to environmental issues like open dumping, greenhouse gas emissions, and the leaching of harmful substances (phenolics, tannins) into soils and water bodies (KIU, 2018).

Meanwhile, the use of chemical (synthetic/inorganic) fertilizers in Uganda especially on coffee, rice, maize and other major crops has been increasing in both importance and intensity as farmers seek higher yields (IFDC, 2014; NUTECH MD study, Northern Uganda). For lowland rice in particular, provisional fertilizer application rates advised can reach 139-205 kg/ha of Urea (\approx 64-94 kg N/ha), 60-175 kg/ha of DAP (\approx 12-34 kg P/ha), and 180-542 kg/ha of MOP (\approx 90-271 kg K/ha) depending on the soil nutrient status (MAK/RIF Project, Namutumba District). However, despite this increasing reliance on chemical fertilizer, soils continue to degrade with negative nutrient balances, erosion, and declining organic matter content, limiting productivity gains (MAAIF, 2024; IFDC, 2014). The cost and accessibility of inorganic fertilizers remain major

constraints for many smallholder farmers, and inconsistent use leads to inefficient nutrient uptake and loss (IFDC, 2014; NU-TEC MD).

This paradox where farmers are applying more chemical fertilizers but still facing declining soil fertility and yield plateaus underscores the need for sustainable, locally available soil fertility restoration options. Composting coffee and rice husks into biofertilizer offer a promising alternative: it could help reduce dependence on costly synthetic inputs, improve organic matter content, and enhance nutrient cycling in soils.

However, composting fibrous residues like coffee and rice husks is challenging because of their high lignin and cellulose content, which make them decompose slowly under traditional composting methods (SCIRP, 2019). Practices that rely heavily on chemical fertilizer often neglect organic matter replenishment, which is crucial for soil structure, moisture retention, and long-term fertility.

Emerging evidence suggests that indigenous microorganisms (IMOs) locally adapted fungi and bacteria can speed up decomposition of difficult residues, improve nutrient availability, and produce higher quality compost. For example, microbial consortia including *Bacillus* spp. in mixtures with rice husks have been shown elsewhere to increase composting rates and crop yields compared to treatments without IMOs (Singh et al., 2019). Yet, there is limited research under Ugandan field conditions on how effective locally adapted microbes (IMOs) are in turning coffee and rice husks into nutrient-rich biofertilizer.

This study thus seeks to fill that knowledge gap by evaluating the potential of indigenous microorganisms to enhance decomposition of coffee and rice husks under Ugandan conditions, and by quantifying how biofertilizer derived from

these residues could supplement or reduce chemical fertilizer requirements for smallholder farmers. The goal is to offer a sustainable pathway that addresses soil fertility restoration and consequently agricultural waste management.

1.3 Study Objectives

1.3.1 General objective

To assess the potential of using indigenous microorganisms (IMOs) in bio conversion of coffee and rice husks in bio fertilizer production.

1.3.2 Specific objectives

1. To determine the decomposition rate of coffee and rice husks when treated with IMOs, using Temperature and CN ratio as an indicator.
2. To evaluate the quality of the resulting biofertilizer from IMO-treated coffee and rice husks based on pH, organic matter, macronutrient content (N, P, K), secondary nutrients (Ca, Mg), and physical properties (texture, odor, color, and moisture content).

1.4. Hypothesis

1. Temperature changes during composting significantly influence the breakdown of coffee and rice husks into biofertilizer
2. IMOs significantly accelerate the decomposition of coffee and rice husks into biofertilizer, as indicated by temperature and C/N ratio
3. IMOs significantly alter the physicochemical properties (pH, organic matter, and nutrient content: N, P, K, Ca, Mg) of the resulting biofertilizer compared to untreated husks.

4. IMO significantly improve the physical characteristics (texture, odor, color, and moisture content) of the biofertilizer compared to untreated husks.

1.5 Significance of the study

The study findings shall be used to make recommendations for converting rice husks and coffee husks into a useful resource (bio fertilizer) that can be used to maintain soil fertility over time and offer a solution to sustainable management of agricultural waste. This way, farmers are using a sustainable way to reduce farm waste and at the same time enriching the soil that will improve soil health, soil productivity and increased crop production.

This study findings are to help key stakeholders like, small holder and commercial farmers of coffee and rice commodities on choice of rice and coffee husks management as a major waste generated in their production.

Also, policy-makers can use this study finding to make recommendation on cost effective and sustainable ways of managing waste.

Furthermore, the results of this study are going to address the knowledge gap especially on the use of indigenous microorganisms for bio-conversion of agricultural waste-rice and coffee husks in particular.

1.6 Scope of the study

This study focused on assessing the effectiveness of indigenous microorganisms in the bio-conversion of agricultural waste (coffee and rice husks) to increase the quality of bio-converted organic fertilizer in Uganda. The study was conducted

at Kyambogo University farm and laboratory analysis was carried out from Jabba soil Laboratories in Ntinda-Kampala. The treatments were Coffee husks+ Goat manure+ IMO, Goat manure +Goat manure, Rice husks+ Goat manure+ IMO and Rice husks+ Goat manure. These were applied as a Completely Randomized design, having soil organic matter, pH, Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Moisture content as major dependent variables for compost quality while temperature was for the decomposition rate.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil fertility

2.1.1 Overview of Soil fertility in Africa

Soil fertility depletion is a key constraint to agricultural productivity in Sub-Saharan Africa (Hena & Baanante, 1999; Sanchez, 2002). Continuous cultivation, soil erosion, leaching, and nutrient mining contribute to declining yields and soil degradation (Stoorvogel & Smaling, 1990). Fertilizer use remains extremely low—averaging 1–2 kg/ha in Uganda compared to 9 kg/ha in Sub-Saharan Africa and more than 100 kg/ha globally (FAOSTAT, 2021).

In Uganda, coffee and rice are particularly vulnerable to nutrient depletion. Coffee cultivation, practiced mainly on smallholder farms, continuously removes potassium, calcium, magnesium, and nitrogen through harvested cherries and pruning materials (Van Asten et al., 2011; Byekwaso et al., 2022). Similarly, rice farming depletes soils through nutrient leaching, denitrification, and removal or burning of rice residues (Dobermann & Fairhurst, 2002; Balasubramanian et al., 2007). Current residue handling methods burning or discarding husks exacerbate nutrient losses, contributing to long-term soil fertility decline.

2.1.2 Factors that influence soil fertility in Africa

Soil Type and Composition:

The inherent physical and chemical properties of soil significantly determine its fertility. Sandy soils, which dominate arid and semi-arid regions, tend to have low nutrient- and water-holding capacities (Bai et al., 2018). Conversely, clay-rich soils may retain more nutrients but are often prone to salinity and poor drainage (Zhou et al., 2019).

Land Use Practices: Unsustainable land use, such as shifting cultivation, overgrazing, and monocropping, has contributed to soil nutrient depletion and degradation. Lal (2004) emphasized that the absence of crop rotation and the continuous removal of biomass without replenishment exacerbate soil fertility loss.

Climate Change: Climate variability poses significant challenges to soil fertility. Increased temperatures and altered precipitation patterns can exacerbate soil erosion and reduce organic matter content (IPCC, 2014). The impacts of climate change are compounded by continental disparities in vulnerability and adaptive capacities (Niang et al., 2014).

2.1.3 Challenges to Soil Fertility in Africa

Improving soil fertility across the continent is challenged by a combination of biophysical and socio-economic constraints:

Nutrient Depletion: Continuous cropping without adequate replenishment of nutrients has resulted in severe nutrient depletion in many regions. A study by

Henao, & Baanante, (1999) noted that agricultural land in sub-Saharan Africa has lost up to 60% of its initial nutrient content.

Policy and Institutional Barriers: Ineffective agricultural policies and lack of access to extension services hinder farmers' ability to implement best practices in soil management. Sukprasert & Phadungkit. (2024) emphasizes the need for innovative policy frameworks that encourage sustainable agricultural practices.

Economic Constraints: Limited access to fertilizers and other soil amendments due to high costs and lack of availability restricts farmers' capacity to improve soil health. The African Fertilizer and Agribusiness Partnership (AFAP) (2019) underlines the need for affordable inputs to enhance soil fertility sustainably.

2.1.4 Innovative Solutions for Enhancing Soil Fertility

In response to the challenges of nutrient depletion and soil degradation, several innovative strategies have been proposed and tested to restore and maintain soil fertility in sustainable ways:

Agroecological Practices

Techniques such as intercropping, cover cropping, and agroforestry enhance soil organic matter, improve soil structure, and increase biodiversity. These practices also provide resilience against environmental shocks while offering economic benefits to farmers (Altieri, Nicholls, & Montalba, 2017).

Organic Amendments

The application of compost, farmyard manure, and green manure enriches soils with organic matter and nutrients. A global meta-analysis demonstrated that organic inputs improve microbial activity, enhance nutrient cycling, and increase yields in degraded soils (Bhunia et al., 2021).

Microbial Inoculants

The use of beneficial microorganisms such as mycorrhizal fungi, rhizobia, and phosphate-solubilizing bacteria can improve nutrient availability and soil health. Inoculation has been shown to enhance nitrogen fixation, phosphorus mobilization, and crop productivity, particularly in nutrient-poor soils (Schütz et al., 2018).

Biofertilizers

Biofertilizers, which include microbial-based products that stimulate nutrient uptake and soil biological activity, represent an eco-friendly alternative to chemical fertilizers. Studies in tropical farming systems show that biofertilizers can increase nutrient-use efficiency and crop yields while maintaining soil fertility (Yadav & Sarkar, 2020).

Precision Agriculture

Advances in precision agriculture technologies, including remote sensing, soil testing, and site-specific nutrient management, allow farmers to apply inputs more efficiently. This minimizes nutrient losses, prevents over-application, and enhances long-term soil fertility (Gebbers & Adamchuk, 2010).

Conservation Agriculture

Practices such as minimum tillage, crop residue retention, and crop rotation conserve soil structure, reduce erosion, and enhance organic matter content. These methods improve water retention and reduce nutrient losses (Kassam, Friedrich, & Derpsch, 2019).

Integrated Soil Fertility Management (ISFM)

ISFM combines organic inputs, mineral fertilizers, and improved crop varieties to optimize nutrient use. This approach has been widely promoted in sub-Saharan Africa to improve soil fertility and productivity in smallholder farming systems (Vanlauwe et al., 2015).

2.1.5 Soil fertility in Uganda.

Soil fertility is a critical factor influencing agricultural productivity in Uganda, a country heavily reliant on agriculture for its economy and food security. The fertility status of soils in Uganda has been the subject of various studies, highlighting both challenges and opportunities for sustainable agricultural practices. One of the primary concerns regarding soil fertility in Uganda is nutrient depletion. According to Nkonya et al. (2016), continuous cropping without adequate replenishment of nutrients has led to significant declines in soil fertility across various regions. The study emphasizes that the over-reliance on traditional farming practices, coupled with limited access to fertilizers, has exacerbated the problem. Furthermore, Soil pH is another critical aspect affecting nutrient availability. A study by Kolle et al. (2018) observed that many soils in Uganda are acidic, which limits the availability of essential nutrients such as phosphorus. The authors suggest that lime application could be a viable solution to improve soil pH and enhance nutrient availability, thereby boosting crop yields. Similarly, according to a review by Fageria, (2012), organic matter would contribute to soil structure, moisture retention, and nutrient supply.

2.2 Soil nutrient mining in coffee and rice farming systems

Soil nutrient mining refers to the depletion of essential nutrients from the soil due to continuous cropping without adequate replenishment (Majumdar et al., 2016). This phenomenon is particularly pronounced in intensive agricultural systems, such as coffee and rice farming, where the demand for high yields often leads to unsustainable practices.

2.2.1 Nutrient Depletion in Coffee and Rice Farming systems

Coffee (*Coffea* spp.)

Coffee is Uganda's major export crop and a significant source of household income. However, nutrient depletion within coffee farming systems remains a critical challenge. Several factors contribute to this problem:

Crop removal: Harvesting and processing of coffee cherries leads to major nutrient export. For example, 1 tonne of clean Arabica coffee removes ~34 kg N, ~2.2 kg P, and ~45 kg K; Robusta removes ~35 kg N, ~3.1 kg P, and ~39 kg K (Monitor, 2018).

Low fertilizer application: Fertilizer use is generally minimal or absent among smallholder farmers, creating a negative nutrient balance (Tully & Lawrence, 2011).

Residue mismanagement: Coffee husks, pulp, and prunings are often not recycled into the soil, leading to reduced organic matter inputs (Kiup, 2017).

Soil erosion: Coffee is often cultivated on sloping terrain without adequate soil conservation, resulting in nutrient losses through runoff.

Export-based nutrient deficit: Uganda's coffee system has been estimated to lose ~87 kg nutrients per hectare annually, broken down into ~38 kg N, 17 kg P, and 32 kg K, largely due to harvest removals and inadequate replenishment (Uganda Journal of Agricultural Sciences, 2013).

Rice (*Oryza sativa*)

Rice is an increasingly important staple crop in Uganda, but continuous cultivation has led to widespread nutrient depletion. The major sources and factors include:

Crop removal and poor residue return: Harvesting of rice grains and straw contributes to substantial nutrient extraction, yet residues are frequently burned or removed from the field (Tran et al., 2024).

Minimal fertilizer use: Fertilizer adoption in smallholder systems remains extremely low, leaving nutrient exports largely unreplaced (ISRIC, 2024).

Monocropping: Continuous rice cultivation without rotations limits biodiversity and natural soil nutrient recovery (Tran et al., 2024).

Indigenous nutrient supply limits: Field omission experiments show that Ugandan rice soils can only supply ~52 kg N, 9.7 kg P, and 87.2 kg K per hectare annually, which is insufficient to balance crop uptake (Mubiru et al., 2025).

Depletion rates: Under current practices, rice systems in Uganda lose ~72 kg N, 23 kg P, and 43 kg K per hectare annually (ISRIC, 2024).

In a nut shell, both coffee and rice farming systems in Uganda are undergoing severe nutrient depletion. In coffee, losses of ~87 kg nutrients per hectare annually (~38 N, 17 P, 32 K) are reported. Rice systems show even higher cumulative losses (~138 kg nutrients/ha/year: 72 N, 23 P, 43 K). The main

drivers are crop removal, insufficient fertilizer use, poor organic residue management, monocropping, and erosion. If unaddressed, these nutrient deficits threaten long-term soil fertility and the sustainability of Uganda's export and staple crop production systems.

2.2.2 Comparative Analysis of Coffee and Rice Farming Systems

Although both coffee and rice farming systems are susceptible to nutrient mining, the nature, severity, and underlying drivers of nutrient depletion differ significantly between the two.

Coffee farming, particularly in traditional systems, is often integrated with agroforestry practices that can partially buffer against nutrient loss. The incorporation of shade trees in coffee plantations contributes organic matter through leaf litter and enhances soil structure, water retention, and biodiversity (Souza et al., 2012). These agroecological interactions can help sustain soil fertility over longer periods, provided the system is properly managed.

Conversely, rice farming especially under intensive monoculture systems tends to exhibit more severe nutrient mining. Continuous cropping cycles, heavy reliance on synthetic fertilizers, and limited incorporation of organic amendments contribute to the rapid depletion of key soil nutrients such as nitrogen (N), phosphorus (P), and potassium (K) (Khatri et al., 2024). Unlike agroforestry-based coffee systems, rice fields often lack biological diversity and organic matter inputs, which diminishes the soil's natural regenerative capacity. Moreover, the practice of monocropping in rice systems disrupts nutrient cycling and limits microbial diversity, further exacerbating fertility decline. The long-term consequence is a growing dependence on external inputs to sustain yields

an approach that is both economically and environmentally unsustainable for many smallholder farmers.

2.2.3 Sustainable Practices to Mitigate Nutrient Mining

To address the issue of soil nutrient mining in both coffee and rice systems, several sustainable practices have been proposed. These include the adoption of cover cropping, crop rotation, and the use of organic amendments such as compost and green manures (Aguilar-Rivera et al., 2023). Integrating these practices can enhance soil fertility, improve water retention, and promote a more resilient agricultural system (Aguilar-Rivera et al., 2023).

2.3 Soil amendments and suitable soil types for their application

Soil amendments are substances incorporated into soil to enhance its physical or chemical characteristics, thereby supporting plant growth and overall soil health (Angelova et al., 2013). The choice of amendment depends on the soil's condition and the particular requirements of the plants being grown.

2.3.1 Organic Amendments

Organic inputs like compost, manure, and green manures are commonly utilized to enhance soil structure, boost nutrient levels, and stimulate microbial activity. For example, compost has been found to improve moisture retention and aeration in sandy soils (Seker et al., 2020). In clay soils, organic amendments can alleviate compaction and promote better drainage (Singh et al., 2022).

2.3.2 Inorganic Amendments

Inorganic soil amendments such as lime, gypsum, and rock phosphate are commonly applied to adjust soil pH and supply vital nutrients. Lime is especially useful in acidic soils, as it increases pH and enhances nutrient availability for plants (Lehmann & Joseph, 2009; Havlin & Heiniger, 2020). Gypsum is effective in treating sodic soils by improving soil structure and lowering salinity levels (Bello et al., 2021).

2.3.3 Biochar

This carbon-rich substance is created through the pyrolysis of organic materials and has attracted interest for its potential to boost soil fertility and store carbon. Research shows that biochar can enhance nutrient retention and increase water-holding capacity in both sandy and clay soils (Jeffery et al., 2011).

2.3.4 Mulches

Organic mulches, such as straw or wood chips, are used to suppress weeds, retain soil moisture, and add organic matter as they decompose. They are particularly effective in sandy soils where moisture retention is a concern (Li % Pan, 2021).

2.3.5 Synthetic Amendments

These include products like polymer-coated fertilizers and soil conditioners that can enhance nutrient availability and improve soil structure. They are often used in a variety of soil types, including loamy and sandy soils, to optimize plant growth (Majeed et al., 2015).

Therefore, the choice of soil amendment depends on the specific soil type and the desired outcomes for plant growth. Ongoing research continues to explore the effectiveness of various amendments in different soil conditions, contributing to sustainable agricultural practices.

2.4 The Economic Significance of Rice and Coffee in Uganda

Rice has emerged as a staple food in Uganda, with its production increasing significantly over the past few decades. According to the Food and Agriculture Organization (FAO), rice production in Uganda has grown due to rising domestic demand and favorable climatic conditions. This growth has not only contributed to food security but has also created job opportunities in farming, processing, and distribution sectors (FAO, 2020).

Coffee is Uganda's top export crop and plays a major role in generating foreign exchange earnings. According to the Uganda Coffee Development Authority (UCDA), coffee exports make up about 20% of the country's total export income. The crop serves as a vital source of livelihood for millions of smallholder farmers and is the main economic activity for numerous rural households (UCDA, 2021).

Both rice and coffee cultivation provide employment opportunities across various levels of the supply chain. The production of rice has led to the establishment of numerous agro-based industries, which further enhances job creation. Studies indicate that rice farming can significantly reduce poverty levels in rural areas by providing stable incomes (World Bank, 2019). Coffee farming supports over 1.7 million households in Uganda, making it a cornerstone

of rural livelihoods. The income generated from coffee sales allows families to invest in education, healthcare, and other essential services, thereby improving their overall quality of life (International Coffee Organization, 2020).

2.5 Utilization of Coffee and Rice Husks: Opportunities and Challenges

Coffee husks contribute 374,000–450,000 tons annually in Uganda, while rice husks exceed 820,000 tons (Heuzé & Tran, 2015; Hong et al., 2021; UCDA, 2023). Current uses include low-grade fuel, animal bedding, or dumping. However, these uses add little value, and environmental problems arise from husk heaps (odor, leachates) or open burning (GHG emissions) (Scarlat et al., 2015).

Challenges in husk utilization:

- High lignin, polyphenol, and tannin content (coffee husks) limits direct soil use and can be phytotoxic.
- High silica levels (rice husks) slow decomposition.
- Lack of nitrogen supplementation reduces composting efficiency in smallholder systems.

Opportunities: Proper composting of husks can recycle nutrients (N, P, K, Ca, Mg) and add organic matter to soils. Rice husk silica may improve plant resistance to pests, while coffee husks provide relatively higher potassium (Juliano, 1985; Kumar & Gopal, 2015). When properly decomposed, husk-based fertilizers can reduce fertilizer dependence and improve soil health.

2.6 Microbial species present in composts, bio fertilizers and indigenous

Microorganism mixtures.

2.6.1 Composts

Composting is a biological process that converts organic waste into a stable, nutrient-rich material through the activity of microorganisms. The microbial community involved in composting plays a vital role in the decomposition process, directly affecting the quality and safety of the final compost product (Aguilar-Paredes et al., 2023). This microbial community is highly diverse and includes bacteria, fungi, actinomycetes, and protozoa. Among these, bacteria are the most prevalent, with common genera such as *Bacillus*, *Pseudomonas*, and *Lactobacillus* frequently identified (Palaniveloo et al., 2020). These bacteria are crucial during the early stages of decomposition, as they break down complex organic substances into simpler forms. Fungi are also important in composting, especially during the later stages of the process. Genera like *Aspergillus*, *Penicillium*, and *Trichoderma* are recognized for their ability to decompose lignin and cellulose, aiding in the stabilization of organic matter (Singh & Nain, 2014). Actinomycetes, a group of filamentous bacteria, are essential for degrading tough plant residues and are responsible for the distinctive earthy aroma of mature compost (Finore et al., 2023).

The makeup of microbial communities in compost is shaped by several factors, including the type of organic materials used, the composting technique, and environmental variables like temperature and moisture levels. For example, thermophilic bacteria are active at higher temperatures during the early stages of

composting, whereas mesophilic bacteria become more prominent as temperatures decrease (Rawat & Johri, 2013). Specific substrates can also influence microbial populations; for instance, incorporating food waste tends to increase the presence of *Bacillus* species, while yard waste may support greater fungal growth (Mironov et al., 2021). Understanding the microbial composition of compost is important for both quality and safety. Some harmful pathogens can survive the composting process, posing a risk of contamination in the final product. Studies have shown that proper composting methods can lower pathogen levels, but continuous monitoring of microbial communities is essential to ensure compost safety, particularly in agricultural applications (Gurtler, Jin, & Mandrell, 2018).

2.6.2 Bio fertilizers

Bio fertilizers are natural fertilizers that contain living microorganisms, which promote plant growth by increasing the availability of nutrients in the soil. They play a crucial role in sustainable agriculture by enhancing soil fertility, improving crop yield, and reducing the reliance on chemical fertilizers (Vessey, 2003).

2.6.2.1 Types of Biofertilizers

Bio fertilizers can be categorized into several types based on the microorganisms they contain;

Nitrogen-Fixing Bio fertilizers

These include bacteria such as *Rhizobium*, *Azotobacter*, and *Frankia*, which convert atmospheric nitrogen into a form that plants can use. Studies have shown

that these bacteria can significantly enhance the nitrogen content in the soil, leading to improved plant growth (Glick, 2012).

Phosphate-Solubilizing Bio fertilizers

Microorganisms like *Bacillus* and *Pseudomonas* species help solubilize phosphate, making it more available to plants. Research indicates that these bio fertilizers can increase phosphorus uptake, which is essential for plant development (Khan et al., 2009).

Mycorrhizal Fungi

Arbuscular mycorrhizal fungi (AMF) establish symbiotic associations with plant roots, aiding in the absorption of nutrients and water. They are especially beneficial in enhancing the uptake of phosphorus and essential micronutrients (Smith & Read, 2008).

2.6.2.2 Benefits of Biofertilizers

The use of bio fertilizers offers several advantages namely;

Environmental Sustainability: Bio fertilizers reduce the need for chemical fertilizers, which can lead to soil degradation and water pollution. Their application promotes a healthier ecosystem (Kumar et al., 2015).

Cost-Effectiveness: Farmers can reduce their input costs by using bio fertilizers, as they are often less expensive than chemical alternatives (Bashan et al., 2013).

Improved Soil Health: Bio fertilizers enhance soil structure and fertility, promoting a diverse microbial community that is beneficial for plant growth (Liu et al., 2023).

In conclusion, bio fertilizers represent a promising alternative to chemical fertilizers, contributing to sustainable agricultural practices. Their ability to enhance nutrient availability and improve soil health makes them an essential component of modern farming strategies.

2.6.3 Indigenous microorganisms

Indigenous microorganisms are naturally occurring microbial communities found in soil and on the surfaces of living organisms, both internally and externally. They possess various capabilities, including biodegradation, bioleaching, composting, nitrogen fixation, enhancing soil fertility, and contributing to the production of plant growth hormones (Kumar & Gopal, 2015).

The Indigenous Microorganism technology was developed by Cho & Koyama (1997) in the 1960s during the 1960s. Indigenous microorganism cultures are mainly composed of beneficial microorganisms that consist of fungi, bacteria, and Actinomycetes which are collected and cultured from soils. These microorganisms are known for living in the soil and all surfaces of living things, a reason as to why they are collected from the soil. Application of Indigenous Microorganisms knowledge in agriculture is an environmentally friendly innovation that helps in enhancing the decomposition of organic matter, plant nutrition, soil fertility, crop yields and resistance to plant diseases (Xa & Nghia, 2020)

The developer of the technology observed tremendous improvements in the soil and plants health after applying indigenous microorganisms (Cho & Koyama,

1997). Chimela et al (2013) as cited by (Xa & Nghia, 2020), in his study found out that Indigenous Microorganisms were very effective in the promotion of agricultural and plant residues degradation in a compost heap and produced micronutrients that can be up taken by plants.

Because of its environmentally friendly benefits, this Indigenous microorganism technology has been widely adopted and used in agricultural applications in many countries around the world (Xa & Nghia, 2020).

2.6.3.1 Importance of Indigenous Microorganisms

Indigenous microorganisms are not just a culture of single microorganisms but rather a mixture of beneficial microorganisms that live together in harmony in nature. This Indigenous microorganism technology is a robust innovative approach for sustainable and environmentally friendly farming (Kumar & Gopal, 2015).

The ability of these Indigenous microorganisms to biodegrade organic materials, fix Nitrogen and improve soil fertility makes them stand out as one of the key contributors to healthy soils and the ecosystem at large. Indigenous microorganisms increase the availability of nutrients to plants and also increase the water holding capacity thereby by keeping the soil with optimum moisture for plants (Abu-Bakar & Ibrahim ,2013).

The activities of these microorganisms in the soil improve soil porosity thus improved aeration and proper gaseous exchange in the soil which at the same time contributes to the life of these microorganisms in the soil (Baduru & Gopal, 2015). Indigenous microorganisms are also known for protecting plants from

pathogenic microorganisms which are very hazardous due to their potential for causing disease. They create an antagonistic environment by producing bacteriocins and other substances that inhibit the presence of these pathogenic microorganisms (Baduru & Gopal, 2015).

Therefore, need for soil amendments is ever increasing and interconnected with the increase in production and acreage under coffee and rice production. So environmentally friendly processes are being promoted in all agricultural systems. Therefore, efforts to evaluate the potential of using IMO to speed up the decomposition process of coffee and rice husks is a critical innovation.

2.7 Factors that speed up the rate of decomposition

When preparing compost, we must consider the Carbon to Nitrogen, Aeration, temperature, residue size and size of the compost pile.

2.7.1 Carbon : Nitrogen (C : N) ratio.

Carbon and nitrogen are both basic constituents of organic matter. Carbon is present in dry materials such as leaf litter, stubble, straw, garden waste dried, coconut fibers, shavings, cardboard and chopped paper while Nitrogen is present in greater quantities when organic materials are green just like when the excrements are fresh.

The recommended value of the C: N ratio to obtain quality compost is found estimated between 25:1 and 40:1 (Meena et al,2021).

This means that they will be added to the composting process 25 or 40 parts carbon to 1-part nitrogen. This component ratio must be taken into account to obtain a quality bio fertilizer.

2.7.2 Aeration

During the composting process, management conditions promote the decomposition through various natural biological processes that require special conditions of humidity, aeration and temperature. Oxygen supply in particular should be adequately maintained since it is very essential in the growth and activity of microorganisms which play a key role in the breakdown of organic matter and heat production. This is how turning during composting becomes an important aspect during composting-it moderates the heat in the compost and also enables oxygen supply. (Meena, et al,2021).

2.7.3 Temperature

Microbial activity will produce an increase in temperature as a result of the exothermic biological oxidations and, since organic matter has very poor thermal conductivity, it acts as a thermal insulator, causing most of the heat produced to remain within the pile of organic material. The compost will cool down subsequently by decreasing decomposition. Temperatures keep varying during the composting process due to the compost maturation phases (Meena et al.,2021).

While composting is considered to be the most conventional technique for organic residues on a large scale, it can be boosted by using inoculants like

indigenous microorganism to further accelerate decomposition and increase the decomposition rate (Zainudin et al, 2022).

2.7.4 Residue Size

Particle size determines how easily microbes degrade an organic residue. Smaller particles are easier to degrade, causing their decomposition to occur more rapidly. They are also well aerated and able to retain more moisture in between their surfaces. Therefore, shredding the materials before adding them to the compost pile is always a good idea. An optimum size of two inches or less in the largest dimension for efficient composting (Mishra et al, 2022).

2.7.5 Size of the Compost Pile

The size and volume of the compost pile is important because it affects the temperature regulation, aeration, and moisture retention properties of compost systems. Large-sized compost piles lose their heat and moisture too quickly to the atmosphere plus excessive aeration interrupts the activity of bacteria and Actinomycetes. On the other hand, extremely small compost bins heat up too quickly, plus lack of aeration and high moisture retention can spur anaerobic activity within them. To avoid all of these issues, a moderate-sized Compost pile is recommended. An ideal composting bin should be three to five square feet in size (Aziz et al.,2018).

2.8 The composting phases

By decomposing Carbon (C), Nitrogen (N) and all organic matter initially, the microorganisms give off heat. Depending on the temperature generated during

the process, three main stages are recognized in composting, in addition to a fourth stage of maturation (Nemet & Lončarić, 2021).

2.8.1 Mesophilic stage

It is the first phase of the composting process which begins under the impact of thermophilic bacteria at room temperature. The temperature then rises rapidly to 45°C and due to microbial activity, the biodegradation process begins. This phase is takes place during the first days (between two and eight days) (Villar et al., 2016).

2.8.2 Thermophilic phase

During this stage, the temperature remains relatively high as a result of heat generated by microbial activity. Thermophilic bacteria, which thrive in elevated temperatures, are responsible for breaking down more complex carbon compounds like cellulose and lignin. This phase, often referred to as the "sanitization phase," can last from several days to a few months, depending on factors such as the type of organic material used, climate, site conditions, and other variables. The high temperatures reached during this period help eliminate harmful bacteria and potential fecal contaminants present in the initial material (Villar et al., 2016).

2.8.3 Cooling or mesophilic phase

The temperature begins to decrease to 45 °C again, so the process of biodegradation proceeds more slowly and emissions also decrease. In general, there is no need for aeration or humidification during this phase, but it may be

advisable to continue mixing, turning and moving the material to obtain a homogeneous and hygienic product. This phase requires several weeks and it can easily be confused with the last phase of the process (Villar et al, 2016).

2.8.4 Maturation phase

It requires several months at room temperature, a time for production of secondary condensation and polymerization reactions of carbon compounds for the formation of humic and fulvic acids. During this process there are certain parameters that must be monitored to make excellent quality compost; some of them are: oxygen, carbon dioxide, humidity, temperature and pH, among others (Villar et al., 2016).

2.9. Indigenous Microorganism's (IMO's) Contribution to the decomposition process and their importance in coffee and rice husks

Indigenous Microorganisms (IMOs) are naturally occurring microorganisms that play a crucial role in the decomposition of organic matter and nutrient cycling in ecosystems. Their significance extends beyond natural ecosystems into agricultural practices, where they enhance soil health, improve crop yields, and promote sustainable farming practices.

2.9.1 Contribution of IMOs in the Decomposition Process

The decomposition process is vital for nutrient recycling in ecosystems, and IMOs are key players in this process. According to Higa (1994), IMOs facilitate the breakdown of organic materials through their diverse metabolic activities, which include the production of enzymes that degrade complex organic

compounds. This enzymatic action not only speeds up the decomposition process but also boosts nutrient availability for plants. According to a study by Lee et al. (2004), Indigenous Microorganisms (IMOs) aid in the formation of humus—a stable form of organic matter that enhances soil structure and fertility. Incorporating IMOs into composting has been shown to accelerate decomposition and improve the overall quality of the resulting compost (Higa & Wididana, 1991). This is especially valuable in organic farming, where the effectiveness of soil amendments has a direct impact on crop yield.

The agricultural sector benefits significantly from the application of IMOs. They enhance soil microbial diversity, which is crucial for maintaining soil health and resilience (Gomiero et al., 2011). IMOs can improve soil aeration, water retention, and nutrient availability, leading to healthier crops and higher yields (Kumar et al., 2017). Furthermore, the use of IMOs in agriculture promotes sustainable practices by reducing the need for chemical fertilizers and pesticides. A study by Saha et al. (2018) found that farmers who incorporated IMOs into their farming practices reported improved soil fertility and reduced pest incidence, leading to lower input costs and increased profitability. Additionally, IMOs play a role in enhancing plant growth through mechanisms such as the production of plant growth-promoting substances and the suppression of soil-borne pathogens (Bashan & Holguin, 1998). This is particularly beneficial in organic farming systems, where the reliance on synthetic inputs is minimized.

Therefore, Indigenous Microorganisms play a crucial role in the decomposition process and are vital to the agricultural sector. Their capacity to improve soil health, enhance nutrient cycling, and support sustainable farming highlights their significance in contemporary agriculture. Ongoing research and use of IMOs

have the potential to create more resilient farming systems and help ensure food security.

2.10 Coffee production in Uganda

Coffee Plays an important role in Uganda's economy and has become part and partial of the livelihoods of Uganda's local population. Uganda is one of the world's major coffee producers and according to International Coffee Organization (2015).

Uganda was ranked the fourth after Burundi, Ethiopia and Honduras in the share of total coffee export earnings with an average of 18% for the period between 2000 and 2012. Uganda majorly produces Robusta coffee but also grows Arabica in different highland areas of the country especially in the slopes of Mount Elgon.

Robusta is also largely grown in central region mainly in the districts of Luwero, Mityana, Masaka, Kayuga, Rakai, Mubende and Kiboga. Arabica coffee is mainly grown around Mountain Elgon and in the districts of Bushenyi, Ntungamo, Mbera, Kasese, Rukungiri and Mbarara. Some Arabica coffee is also grown in the West Nile region Lira. In 2023, coffee production was about 374,769 tons (Verter et al., 2015).

2.10.1 Coffee processing in Uganda

In Uganda, coffee mainly goes through primary processing which aims at extracting the coffee beans as a major product that is always used for further

processing to produce coffee powder, a product that is used for human consumption.

There are two major processes that coffee cherries undergo two main processing methods: wet processing and dry processing. Wet processing includes steps such as removing the pulp and mucilage, washing, drying, hulling to remove the parchment and film, and grading to produce clean coffee of the desired quality. Dry processing primarily involves drying the cherries, typically in the sun, followed by mechanically removing the dried husks through hulling. Both methods produce waste, mainly consisting of coffee husks.

2.10.2 Physiochemical characteristics of coffee husk

A coffee husk is the dried husk of the coffee cherry that is derived from the natural or dry processing method. Coffee husk is rich in organic substances which include proteins, minerals and carbohydrates which can be explored and used for different purposes such as animal feed and industrial raw material.



Figure 2.1: Photo of coffee husks

Coffee husks can also be used as substrates to produce enzymes, aroma compounds, edible mushroom plant hormones and organic fertilizers (Genet, 2021).

In Uganda, these husks are commonly used as bedding for chicken or burnt to reduce its volumes. These husks are rarely used for manure due to their composition that makes them take long to decompose and they end up as harmful waste to the environment yet they can be transformed to a very useful bio fertilizer that can be added back to the soil.

Coffee has a waste-to-weight ratio of 0.2, meaning it generates about 46.6 metric tons of husks annually, contributing significantly to environmental pollution. These husks are characterized by low bulk density, a high carbon-to-nitrogen (C/N) ratio, and the presence of harmful substances such as tannins, phenolic compounds, caffeine, lignin, and polyphenols, which limit their usefulness and pose serious environmental concerns. Studies show that coffee husks contain over 9% phenolic compounds, and when directly applied to soil, they can hinder root development and lead to increased greenhouse gas emissions due to anaerobic decomposition (Fakadu et al., 2013).

Therefore, it is very of high importance to manage these coffee husk waste for sustainable production and reduced environmental contamination. Coffee husks can be a good soil conditioner when composted because of their nutrient composition that is good for agricultural purpose. Coffee husks contain 0.41% of Nitrogen, 0.29% of Phosphorus and 1.47% of Potassium and other macronutrients.

Composting is one of the most suitable ways farmers can use to convert waste like coffee husks into an important resource for production and productivity.

2.10.3 Rice production in Uganda

Rice is a staple food eaten by half of the world population and is among the top ten (10) most produced commodities in the world. Asia remains the leading producer of paddy rice with China, India and Indonesia being the top 3 producers of rice.

In Uganda, rice is becoming a primary food source for a bigger part of its population and therefore its production has been enhanced; Production of paddy rice in Uganda in 2021 stood at 350,000 MT. Rice consumption stands at per capita consumption of 7.75 Kg per person per year.

Rice is mainly grown in Uganda as a cash crop in the swampy areas around Lake Kyoga. It is estimated that some 400,000 farmers are involved in rice production throughout the country. Rice is mainly largely grown in two areas that is; Kibimba in Bugiri District, Doho in Butaleja District and Olweny in Lira District. About 90% of Uganda rice is produced in the Eastern and Northern regions (Akongo et al., 2017).

All this paddy rice production equates to tons of rice husks, in fact Uganda produces 70,000 tonnes of rice annually. This keeps increasing overtime due to the increased demand for rice by the increasing population. In Uganda, Rice husks are commonly disposed by either burning or burying them in the ground and this contributes a lot to environmental pollution.

2.10.3.1 Rice processing

Rice goes through primary processing which mainly involves threshing, drying, sorting and bagging. Threshing is process by which paddy rice is removed from their stems often by mechanical means or manually by constantly beating them with a stick. This activity is followed by drying of the paddy rice for about 3 days depending on the humidity and once it is dry, it is sorted and bagged for milling. Milling is the last stage of rice processing- at this stage rice grains, bran and husks are got as major products and bi-products.

2.10.3.2 Physiochemical composition of rice husk

The rice husk is the outer layer of the paddy grain that is removed from the rice during the milling process (Finance Tribune, 2015).

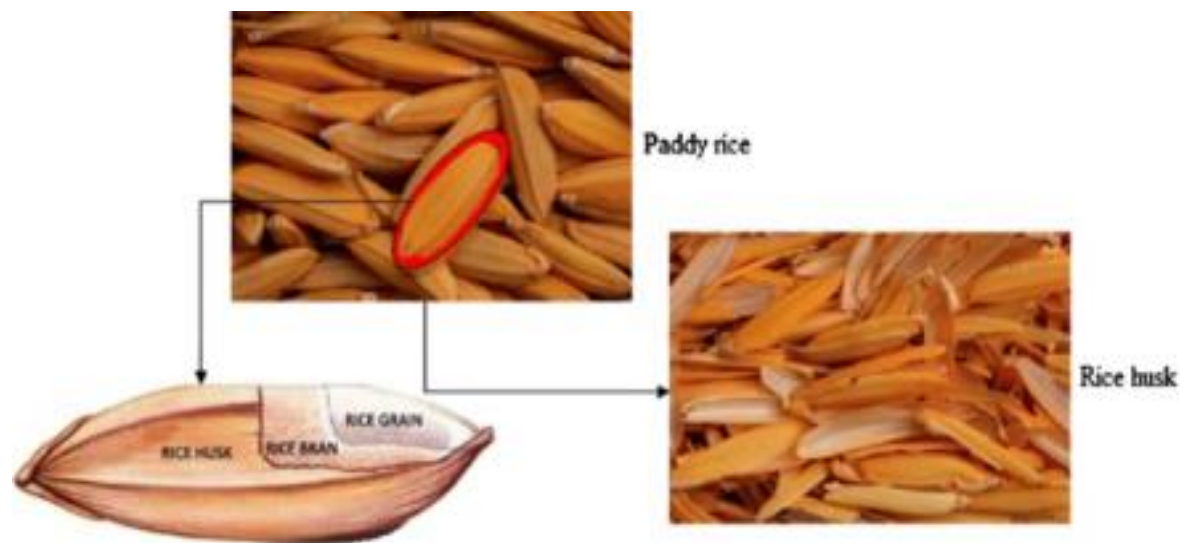


Figure 2.2: Image of rice husks (Source: Encyclopedia)

It is the coating on a seed or grain of rice formed from hard materials, including silica and lignin, to protect the seed during the growing season (IRRI, 2020).

Rice husk typically consists of about 80% organic material, and it accounts for roughly 20–22% of a rice grain's total weight. It contains nearly 20% silica, mostly in a hydrated form (Javed & Naveed, 2008). As noted by Bisht et al. (2020), rice husk is naturally rigid, fibrous, water-resistant, and abrasive due to its silica-cellulose composition. These characteristics make it slow and difficult to decompose naturally, which is why farmers often resort to burning or burying it.

However, farmers can benefit from these husks by exploring the composting technology using indigenous microorganisms which can accelerate and enhance the decomposition process.

2.11 Composting

In agricultural operations here in Uganda, it is very common that due to lack of knowledge on composting, and lack of adequate space and time, the waste generated from crops during post-harvest and after harvest is usually burnt, buried or the material is abandoned outdoors until it rots. However, composting provides the possibility of safely transforming organic waste into inputs for agricultural production.

Composting majorly involves the breakdown of organic waste in the presence of microorganisms which are bacteria, fungi and Actinomycetes. (Billy, 1914).

These microorganisms operate at different temperature stages. For instance, mesophilic microorganisms, which thrive at moderate temperatures, initiate the decomposition process by rapidly breaking down soluble and easily degradable

compounds. This activity generates heat, leading to a rapid increase in the compost's temperature.

Elevated temperatures speed up the degradation of key structural components in plants, such as proteins, fats, and complex carbohydrates like cellulose and hemicellulose. Over time, these substances diminish or are completely broken down, leading to a drop in temperature. This shift creates suitable conditions for mesophilic microorganisms to re-emerge and complete the final stage of curing the remaining organic material (Tang et al., 2007).

This breakdown by microorganisms brings about changes in the physical and chemical composition of the compost

Bacteria and fungi play a key role in decomposing complex organic materials because they release enzymes that help break down substances that are otherwise difficult to degrade, while absorbing simpler compounds into their cells. As coffee and rice production expands in both scale and area, the demand for soil amendments continues to grow. To address this sustainably, eco-friendly practices are increasingly encouraged across agricultural systems. Consequently, exploring the use of Indigenous Microorganisms (IMOs) to accelerate the decomposition of coffee and rice husks represents an important and innovative approach.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site and location

A field experiment was conducted from June to December 2022 at Kyambogo University Farm. The Farm is located on the eastern side of the university main campus at an altitude of 1189 meters above sea level, at coordinates 0°20'54" N and 32°37'49" E (Latitude 0.348334 and Longitude 32.630275). (<https://en.wikipedia.org/wiki/Kyambogo>). The soils in the area are dark, reddish brown, sandy loams (Ekwaro et al., 2019).

Climate

Kyambogo University, situated in Kampala, experiences a tropical rainforest climate (Af) according to the Köppen-Geiger classification. One characteristic of Kampala's climate is the presence of two distinct rainy seasons each year. Although the city doesn't have a clearly defined dry season, it receives more rainfall from August to December and again from February to June. The period from February to June sees particularly high monthly rainfall, with April usually recording the highest average precipitation at approximately 169 millimeters (6.7 inches) (Wikipedia, 2025).

3.2 Experimental design

Coffee husks+ goat manure was combined in a ratio of 1:0.5, respectively. Then coffee husks+ goat manure +Indigenous Microorganisms were mixed for the treatment with Indigenous microorganisms, on a dry weight basis and properly mixed for a total weight of 25 kg for each composting pit. Rice husks+ goat

manure was combined in a ratio of 1:0.5, respectively. Then rice husks+ goat manure +IMO's were mixed for the treatment with IMO, on a dry weight basis, and properly mixed for a total weight of 25 kg for each composting pit. For treatments with IMO, 1 litre of IMO solution was sprinkled onto the compost mixture in the pits, while plain water was used as the control.

Each composting pit contained a total of 25 kilograms of material prepared on a dry-weight basis. For treatments involving coffee husks, 16.7 kg of coffee husks were mixed with 8.3 kg of goat manure in a 1:0.5 ratio, while for the IMO-enhanced treatment, 1 liter of Indigenous Microorganism (IMO) solution was added to the mixture. The same ratio and total weight were applied for rice husk treatments. Prior to treatment application, all replicates were moistened with 2 liters of water to achieve uniform moisture distribution.

The ratio and total weight were selected to maintain an optimal carbon-to-nitrogen (C/N) ratio of approximately 30:1, which is essential for efficient microbial activity and balanced composting of high-carbon agricultural residues like coffee and rice husks. Goat manure, being rich in nitrogen, was incorporated to offset the high lignin and cellulose content of the husks, enhancing microbial decomposition and nutrient mineralization. The 25 kg total mass per pit ensured adequate bulk for heat retention during the thermophilic phase while maintaining good aeration and manageable pit depth for manual turning. This approach aligns with composting recommendations by Bernal et al. (2009) and FAO (2018), which emphasize maintaining balanced C/N ratios and optimal pile volumes for effective compost stabilization.

The compost pits were dressed with plastic bags to prevent the leaching of nutrients from the compost and to prevent water entry, especially during the rainy season. The pits were opened for turning once every month i.e three times during the composting period to allow room for aeration and regulate the temperature in the pit. Two replicates were not opened for turning, so the difference between turning and not turning during pit composting could also be observed. Treatments were arranged in a Completely Randomized Design with five replications (i.e., 20 experimental units).

REP 1	REP 2	REP 3	REP 4	REP 5
D RH+GM	A CH+GM+I	B CH+GM	C RH+GM+I	D RH+GM
A CH+GM+I	D RH+GM	C RH+GM+I	B CH+GM	C RH+GM+I
C RH+GM+I	B CH+GM	D RH+GM	A CH+GM+I	B CH+GM
B CH+GM	C RH+GM+I	A CH+GM+I	D RH+GM	A CH+GM+I

RH+GM is Rice husk+ Goat manure, CH+GM+I is Coffee husks+ Goat manure+ indigenous microorganisms, CH+GM is Coffee husks+ Goat manure, RH+GM+I is Rice husk+ Goat manure+ indigenous microorganisms.

3.3. Preparation of materials to use

3.3.1. Source of microorganisms

To obtain a natural source of beneficial microorganisms, decomposing organic material was collected from a forested area near the Kyambogo University farm. This environment was selected to ensure the microbial culture originated from a natural soil ecosystem conducive to microbial diversity and proliferation.

A starter mix for indigenous microorganisms (IMO) was then prepared by combining approximately one-quarter of a sack of decomposed forest leaf litter with 10 kg of maize bran and 1 liter of molasses. 3 liters of clean water were added to this mixture to achieve the desired moisture level. Moisture content was considered optimal when a handful of the mixture could be pressed into a ball that held its shape but easily crumbled without water dripping through the fingers—consistent with the method described by Abu-Bakar and Ibrahim (2013).

3.3.2. Preparation of Aerobic microorganisms

The prepared mixture of decomposing forest leaves, maize bran, and molasses was divided into two equal portions. One portion was designated for the cultivation of aerobic indigenous microorganisms. To encourage microbial activity while minimizing contamination, this mixture was initially covered with banana leaves. This covering helped regulate internal temperature and protected the substrate from environmental fluctuations and interference by animals during the first 24 hours.

By the second day, the internal temperature of the mixture began to rise noticeably, indicating the onset of microbial activity. Over the next eight days, the mixture was turned regularly to ensure adequate aeration, which is essential for the proliferation of aerobic microorganisms. After this active composting period, the material was transferred into a breathable sack and securely covered.

Within two days of storage, visible white fungal mycelia appeared along with a distinct moldy aroma both reliable indicators of successful microbial

reproduction. At this stage, the IMO culture was considered mature and ready for application.

3.3.3 Preparation of Anaerobic microorganisms

The second portion of the mixture was used to cultivate anaerobic indigenous microorganisms (IMOs). The solid mixture was tightly packed into a clean, airtight plastic bucket to eliminate air pockets and prevent oxygen from entering, which is essential for promoting anaerobic microbial activity. The container was then sealed and stored in a cool, dry place to allow the fermentation process to occur under stable, oxygen-free conditions.

The mixture was left undisturbed for a period of 30 days. At the end of this period, the anaerobic IMO culture exhibited a characteristic fermented odor, indicating successful microbial development. The material was then considered ready for use as a bio-inoculant in composting or soil enhancement.

3.3.4 Activation of Indigenous microorganisms

To activate the indigenous microorganisms (IMOs), a mixture was prepared by combining 2 kg of anaerobic IMO, 1 kg of aerobic IMO, and 1 liter of molasses. These ingredients were thoroughly mixed in a drum containing 20 liters of clean water, and the solution was stirred vigorously to ensure uniform distribution of the microbial cultures and nutrients.

The mixture was then stored in a cool, shaded area protected from direct sunlight and rainfall to maintain optimal fermentation conditions. It was left to stand undisturbed for 48 hours to allow activation of the microbial community.

After this period, the solution now containing actively reproducing microorganisms—was considered ready for application (see Figure 4)



Figure 3.1: Standing drum with 20 litres mixture for activation of indigenous microorganisms.

3.4 Preparation of agricultural waste

The agricultural waste materials used were rice husk, coffee husk, and goat manure, which were used without any prior processing needed.

3.4.1 Coffee husks

Coffee husks used in this study were obtained from coffee-producing areas in Uganda's central region, specifically Mukono District. The husks were collected from local coffee milling facilities, where most farmers bring their harvested coffee for dehusking and other value addition processes. These locations were

selected because they serve as primary collection points for coffee processing waste.

Coffee husks were chosen for this study due to their availability, abundance, and underutilization as agricultural waste in coffee-growing regions. Coffee production generates a substantial amount of husk waste, with a waste-to-product ratio of 0.2 by weight. This translates to an estimated 46.6 metric tons of coffee husks produced annually in Uganda (Fakadu et al., 2013), making it a significant and accessible resource for composting and bio-fertilizer development

3.4.2 Rice husks

Rice husks used in this study were collected from major rice-producing districts in the eastern region of Uganda, specifically Bugiri and Namutumba Districts. The husks were sourced from rice milling facilities, where farmers typically take their paddy rice for processing and value addition. These milling stations were ideal collection points due to the large quantities of waste they generate consistently during the dehusking process.

Rice husks were selected for this study because of their availability, accessibility, and abundance as agricultural waste in rice production areas. In 2021, Uganda's paddy rice production reached approximately 350,000 metric tons, contributing significantly to both domestic consumption and income generation for smallholder farmers. With a per capita consumption of 7.75 kg per year, rice remains an important food and cash crop in Uganda. It is predominantly cultivated in swampy lowland areas, especially around the Lake Kyoga basin

(Akongo et al., 2017), making rice husks a reliable and underutilized resource for sustainable composting and biofertilizer production.

3.4.3. Goat manure

Goat manure used in this study was sourced from the Kyambogo University farm. It was incorporated into the composting process to improve the carbon-to-nitrogen (C/N) ratio, enhance microbial activity, and accelerate the decomposition of fibrous crop residues such as coffee and rice husks.

Additionally, goat manure contributes essential nutrients, thereby enriching the overall quality of the resulting bio-fertilizer (Benbi & Khosa, 2014) (Figure 4).



Figure 3.2: Goat Manure

3.5. Management of the decomposition process

3.5.1 Preparation of composting pits

Decomposition was carried out in open-environment pits, which were dug at a depth of 100 cm and width of 60 cm (Figure 5). The pits were dressed with black polythene to control leaching of nutrients to the soil and to avoid sample contamination with other macro-and microorganisms from the soil (Tumuhairwe et al., 2009).



Figure 3.3:Excavated compost pit.

3.5.2. Operations during composting

During the composting process, temperature monitoring was conducted twice weekly for 12 weeks, specifically at 7:00 AM to track microbial activity and compost maturity across different treatment piles. A digital thermometer was inserted 25 cm deep into multiple points within each compost pile, and the average of these readings was calculated to represent the weekly internal temperature of each treatment.

Regular turning of the compost piles was also carried out to enhance aeration, stimulate microbial activity, and promote uniform decomposition of the materials (Adediran et al., 2003). This practice was essential in maintaining optimal conditions for effective biodegradation and ensuring the production of high-quality compost.

3.6 Laboratory analysis

Compost harvesting for all treatments was carried out after three months, once the internal temperatures of the piles had dropped below ambient levels, indicating the completion of the composting process. The harvested compost was then spread out on clean, dry sacks to allow for further moisture reduction, preparing it for laboratory analysis.

From each treatment, 500 grams of compost were sampled from the various replications. The samples were packed in clean white polythene bags, clearly labelled, and prepared for transport to the laboratory for physico-chemical analysis.

3.6.1. Physical conditions of the material

The physical characteristics such as moisture content, texture, color and odor were analyzed. The moisture content was analyzed by thermo gravimetric method in which 100 grammes of compost material to be measured was weighed and oven dried for 24 hours at 60°C, after which the loss in weight between initial and final weight of material was used to calculate the percent of water available in initial sample (Faithfull, 2002)., texture by the feel method as described by the procedure of (Moorberg % Crouse, 2021; Richer-de-Forges et al., 2024), in

which a handful of the compost material was scooped and moistened to until it could be rolled into a thin finger sized ribbon which was bent into an 8cm circle, which if it had clear large cracks then the compost had not entirely decomposed properly and if there were smaller cracks with less visible large particles then the compost had the most desirable smooth texture, color and odor by visual inspection which was done by physical smelling and observing of the compost for presence of an earthy smell with a brown to dark brown color for well matured composts. (Hidayat et al 2023).

Texture was assessed using the hand-feel and visual observation method, a standard qualitative approach in compost maturity evaluation. This method was chosen because it allows practical assessment of compost physical quality, especially for bulky organic materials like coffee and rice husks, where laboratory-based texture analysis is less feasible. The method aligns with recommendations by FAO (2018) for small-scale composting studies, providing reliable differentiation between coarse, semi-decomposed, and mature compost materials.

3.6.2 Chemical conditions of the material

The chemical characteristics such as pH and nutrient composition (Nitrogen, Potassium, Phosphorus, Calcium and Magnesium) were analyzed by Palintest procedure manual from Jabba Soil Testing Laboratories in Ntinda, Kampala as described by (Handson, 1996).

3.7. Data analysis

The data was processed and tested for normality using the shapiro wilks test for normality, the data for organic matter (%), Nitrogen (%), potassium (%), Phosphorus (%), Calcium (%), and Magnesium (%) was non-normal therefore the data was transformed using the square root function to normalize the data. The least significant difference statistic was used to separate means, respectively. For data turned versus un-turned compost wilcoxon's sign rank test was used to test for differences between the means of the selected parameters for analysis (Shamesh et al., 2010). The statistical software used for statistical modelling was GENSTAT 14.1 Edition.

CHAPTER FOUR

RESULTS AND DISCUSSION

The purpose of this study was to assess the potential of using indigenous microorganisms (IMO) in bio conversion of coffee and rice husks in bio fertilizer production. The outcomes of the investigations were intended to ascertain the potential of using indigenous microorganisms for decomposing coffee and rice crop waste into bio-fertilizer.

4.1 To determine the decomposition rate of coffee and rice husks when treated with IMOs, using Temperature and C/N ratio as indicators.

The rate of decomposition was measured using the changes in temperature

4.1.1 Temperature changes in compost piles during composting process over a duration of 12 weeks.

The initial temperature recorded in the compost pit was 30° C reaching a peak of 51o C in the 5th week. (Figure 4.1)

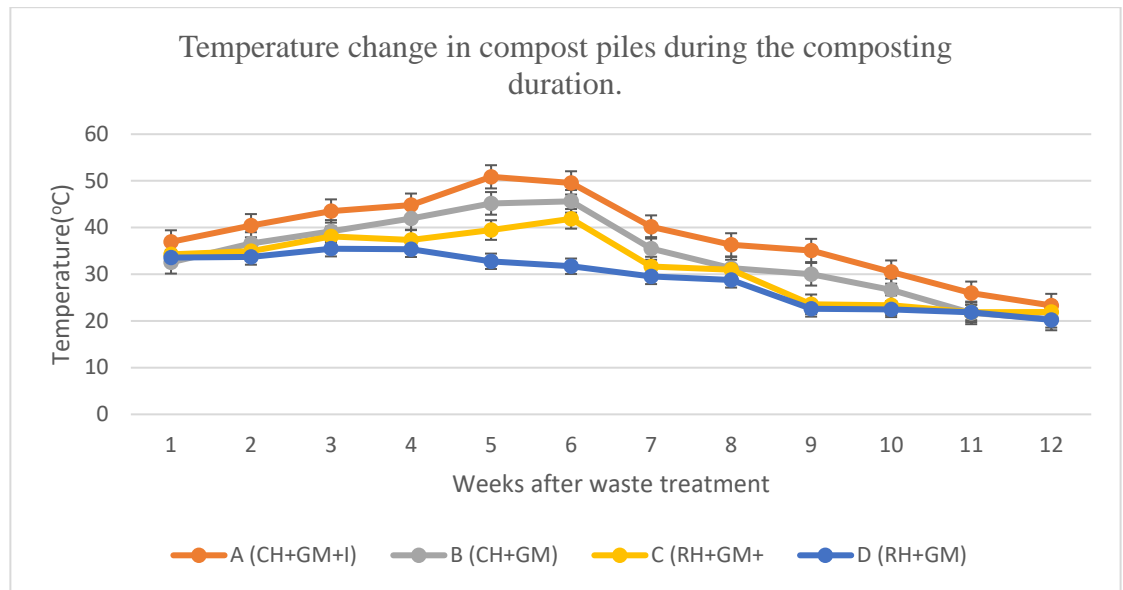


Figure 4.1: Temperature change in four treatments of composting material over 12 weeks.

During the first week, the temperature inside the compost pile ranged from 30–35 °C and gradually increased to between 32 – 40 °C in the second week. By the third week, it continued to rise to a range of 35–43 °C, transitioning from the mesophilic to the thermophilic phase. The temperature further increased, reaching 40–51 °C, before beginning a gradual decline, signaling the onset of the maturation phase. By the twelfth week, temperatures had dropped to between 20 and 30 °C, except in the treatment with rice husk and green manure (RH+GM). Clearly IMO inoculation improves compost pile temperatures. However, the IMO-inoculated treatments consistently showed significantly ($P < 0.05$ input exact probabilities) enhanced temperatures during the composting process.

The composting process in this study revealed that inoculation with Indigenous Microorganisms (IMO) significantly influenced the decomposition dynamics of coffee and rice husks mixed with goat manure. The treatments inoculated with IMO consistently exhibited significantly higher temperatures ($P < 0.05$) throughout the composting period, suggesting that IMO inoculation plays a

crucial role in optimizing composting conditions. These elevated temperatures are primarily attributed to the proliferation of thermophilic microorganisms introduced by the IMO, which thrive in high-temperature environments and enhance microbial metabolism, leading to faster decomposition rates (Park, 2011; Mlangeni, 2013). Such thermophilic activity not only accelerates the breakdown of organic matter but also ensures pathogen destruction, thereby enhancing compost safety and stability (Yengong et al., 2021; Vaddella et al., 2018). These findings align with previous studies documenting that optimal thermophilic composting temperatures typically range between 40°C and 60°C (Chinakwe et al., 2019; Lu, 2013). This underscores the importance of microbial dynamics and temperature regulation in composting, particularly the potential of IMO in enhancing both compost quality and decomposition efficiency.

4.1.2 The change in C/N ratio of the material before and after composting

The change in C/N ration was used as an indicator for rate of decomposition, since it indicates the transformation of lignified materials into readily available nutrients in the soil system. The study results show C/N ratio generally, reduced after three months of decomposition in compost pits among all treatments. (Table 4.1).

Table 4.1: The C/N ratio was analyzed at the beginning of the composting process using the composting material and at the end using the ready product (bio fertilizer).

Treatments	Initial ratio of compost piles	C/N of months decomposition	Final C/N after 3 of
Coffee Husks+ Goat Manure	49		19
Coffee Husks+ Goat Manure+ Indigenous Micro organisms	49		17.3
Rice Husks+ Goat Manure	54		41
Rice Husks+ Goat manure+Indigenous Micro organisms	54		38.6

The final C/N ratio at compost maturity recorded high mean values for Rice Husk+ Goat Manure (RH+GM) followed by Rice husk+ Goat manure + indigenous Microorganisms (RH+GM+IMO), respectively. Similarly, treatment Coffee husks+ Goat manure (CH+GM) recorded the highest mean value followed by Coffee husks+ Goat manure+ Indigenous Microorganisms (CH+GM+IMO). The Rice husk containing treatments overall registered the highest mean C/N ratios when compared to the coffee husk containing treatments, respectively. The study showed that compost treatments containing a mix of rice husks and goat manure (RH+GM) consistently exhibited higher carbon-to-nitrogen (C/N) ratios at the end of the composting period compared to those with coffee husks and goat manure (CH+GM).

The transformation of agricultural waste into organic matter was also accelerated by IMO inoculation. The microbial enzymes produced by indigenous

microorganisms effectively broke down cellulose and other complex plant compounds, releasing carbon in the form of organic matter. The composting efficiency varied with the type of husk used, largely influenced by their initial carbon-to-nitrogen (C/N) ratios. Coffee husks, with a C/N ratio of about 29.8:1, decomposed faster and showed higher organic matter accumulation compared to rice husks, which had a higher C/N ratio of 85:1. The greater nitrogen content in coffee husks supported faster microbial multiplication and increased respiration, leading to a more complete conversion of fibrous residues into stable organic matter. This explains why treatments with coffee husks consistently yielded composts richer in organic matter compared to rice husk treatments.

4.2 The quality of the resulting biofertilizer from IMO-treated coffee and rice husks

In order to evaluate the quality of the resulting biofertilizer from IMO-treated coffee and rice husks, the following parameters were considered; pH of the material, organic matter content, macronutrient content of essential elements (N, P, K), secondary nutrients (Ca, Mg), and selected physical properties (texture, odor, color, and moisture content).

4.2.1 pH of the composted coffee husks and rice husks (bio fertilizer).

The pH was significantly ($p=.017$) raised for the Treatment Rice Husk+ Goat Manure (RH+GM) over treatments Coffee Husks+ Goat Manure (CH+GM), Coffee Husks+ Goat Manure+ Indigenous Microorganisms (CH+GM+IMO) and Rice Husks+ Goat Manure+ Indigenous Microorganisms (RH+GM+IMO).

However, treatment B registered the lowest value among all the treatments. Treatment (CH+GM+IMO) & (RH+GM+IMO), registered values near or above the neutral pH value of 7.0. Therefore, IMO inoculation can raise the pH of a composting pile (Table 4.2).

Table 4.2: Mean values for pH measured at 12 weeks after maturity of compost treated with Indigenous microorganisms.

Treatment	pH
Coffee Husks+Goat Manure	7.1 ^a
Coffee Husks+Goat Manure+Indigenous Micro organisms	6.9 ^{ba}
Rice Husks+Goat Manure	7.5 ^c
Rice Husks+Goat manure+Indigenous Micro organisms	7.1 ^d

Significant differences among means is denoted by different alphabetical letters superscript to the mean values, tested at 5% probability level.

4.2.2 Organic matter content of the composted coffee husks and rice husks (bio fertilizer).

The organic matter was significantly ($p < .001$) improved for both treatments with coffee husks and rice husks mixed with Goat manure plus IMO inoculant. (Table 4.3).

Table 4.3: Mean values of percent organic matter content measured in compost at 12 weeks after addition of indigenous microorganisms

Treatment	Organic Matter (%)
Coffee Husks+ Goat Manure	29.43 ^a
Coffee Husks+ Goat Manure+ Indigenous Micro organisms	37.17 ^b
Rice Husks+ Goat Manure	19.57 ^c
Rice Husks+ Goat manure+ Indigenous Micro organisms	20.23 ^{dc}

Significant differences among means is denoted by different alphabetical letters superscript to the mean values, tested at 5% probability level.

The treatment Coffee Husks+ Goat Manure+ Indigenous Microorganisms (CH+GM+IMO) recorded the highest organic matter (OM) content among the Indigenous Microorganism inoculated treatments Coffee Husks+ Goat Manure+ Indigenous Microorganisms (CH+GM+IMO) & Rice Husks+ Goat Manure+ Indigenous Microorganism (RH+GM+IMO) and non-Indigenous Microorganisms inoculated treatments Coffee Husks+ Goat Manure (CH+GM) & Rice Husks+ Goat Manure (RH+GM) inoculated treatments respectively. Overall the IMO inoculated treatment increased the Organic Matter content of the composts (Table 1).

4.2.3 Macro & micro-nutrients of the bio fertilizer

Table 4.4 summarizes the macro- (N, P, K) and micro-nutrient (Ca, Mg) contents of the different compost treatments, showing significant increases ($p < .001$) across all nutrients. The IMO-inoculated treatments, particularly

CH+GM+IMO, exhibited the highest nutrient concentrations compared to non-IMO treatments.

Table 4.4: Mean values of N, P, K, Ca, &Mg measured at 12 weeks after maturity of compost

Treatment	N(%)	P(%)	K(%)	Ca(%)	Mg(%)
Coffee Husks+ Goat Manure	4.50 ^a	1.13 ^a	2.19 ^a	0.89 ^a	1.26 ^a
Coffee Husks+ Goat Manure+ Indigenous Micro organisms	5.67 ^b	3.31 ^b	2.83 ^{ba}	1.71 ^b	2.27 ^b
Rice Husks+ Goat Manure	0.39 ^c	0.19 ^c	0.33 ^{cb}	0.22 ^c	0.67 ^c
Rice Husks+ Goat manure+ Indigenous Micro organisms	0.75 ^{dc}	0.32 ^{dc}	0.42 ^{dc}	0.59 ^{dc}	1.07 ^d

Significant differences among means is denoted by different alphabetical letters superscript to the mean values, tested at 5% probability level.

The macro-nutrients N ($p<.001$), P ($p<.001$), K ($p<.001$) and micro nutrients Ca ($p=.002$), Mg ($p<.001$), were significantly increased among all treatments. Treatment Coffee husks+ Goat Manure+ Indigenous Microorganisms (CH+GM+IMO) registered the highest values overall. However, the IMO inoculated treatment Coffee husks+ Goat Manure+ Indigenous Microorganisms (CH+GM+IMO & Rice Husks+ Goat Manure+ Indigenous Microorganisms (RH+GM+IMO) consistently improved the nutrient content in compost at maturity than the non-IMO inoculated treatments for N, P, K, Ca, & Mg. The treatment (RH+GM) consistently produced low values for N, P, K, Ca, & Mg content in compost at maturity (Table 4.4).

4.2.4 Moisture content of bio fertilizer

Table 4.5 presents the moisture content of the different compost treatments, showing significant variation ($p < .001$) among treatments, with CH+GM recording the highest values followed by CH+GM+IMO, RH+GM+IMO, and RH+GM.

Table 4.5: Mean values of percent moisture percent moisture content measured in compost after 12 weeks of composting

Treatment	Moisture content (%)
Coffee Husks+ Goat Manure	35.80 ^a
Coffee Husks+ Goat Manure+ Indigenous Micro organisms	34.93 ^{ba}
Rice Husks+ Goat Manure	8.60 ^c
Rice Husks+ Goat manure+ Indigenous Micro organisms	9.53 ^{dc}

Significant differences among means is denoted by different alphabetical letters superscript to the mean values, tested at 5% probability level.

Moisture content was remarkably improved ($p < .001$) among the treatments. Interestingly treatment Coffee Husks+ Goat manure (CH+GM) recorded the highest moisture content among all treatments, followed by Coffee husks+ Goat manure+ Indigenous Microorganisms (CH+GM+IMO), Rice Husks+ Goat Manure+ Indigenous (RH+GM+IMO) & Rice Husks+ Goat Manure (RH+GM) respectively (Table4.5).

4.2.5 Physical characteristics of Agricultural waste after composting

The physical characteristics of the composted materials varied notably depending on the treatment applied. Table 4.6 presents the observed texture, color, and odor of compost produced from coffee and rice husks under different treatment conditions, highlighting the improvements associated with the use of indigenous microorganisms (IMO).

Table 4.6: Physical conditions of the agricultural waste after 12 weeks of decomposition

Treatments		Texture	Color	Odor
Coffee Manure	Husks+Goat	Soil like	Dark brown	Earth smell
Coffee Manure+Indigenous Micro organisms	Husks+Goat	Smoother	Greyish-dark brown	Earth smell
Rice Manure	Husks+Goat	Very rough	Brown	Foul smell
Rice manure+Indigenous Micro organisms	Husks+Goat	Rough	Light brown	Foul smell

The results indicate that coffee husks treated with indigenous microorganisms (IMO) had a smoother texture, a greyish-dark brown color, and an earthy smell, which is an indicator of good compost. Meanwhile, coffee husks without IMO treatment exhibited an earthy smell for the matured compost, but their texture was not as smooth as that of the compost treated with IMO. On the other hand, rice husks exhibited a foul smell and rough texture (Davis & Morris, 2019).

4.3 Discussion

In addition to temperature, pH levels in the compost piles were positively influenced by IMO application. The observed pH values were near neutral, an indication that IMO inoculation in mixtures of coffee and rice husks with facilitated the production of compost suitable for crop growth. Neutral pH levels are critical because they enhance nutrient availability and can help ameliorate acidic soils. The rise in pH is partly due to the increased solubility of essential nutrients such as phosphorus under slightly alkaline conditions (Angelova et al., 2013; Siswanto, 2024). Furthermore, regular turning of compost piles contributed to higher pH levels compared to unturned piles, showing that proper aeration significantly promotes microbial activity and facilitates ammonia production during the early stages of composting (Heyman et al., 2019). However, excessive alkalinity could lead to nitrogen losses through volatilization (Michael, 2021; Loper et al., 2013). Therefore, while IMO and aeration improve compost quality through pH adjustment, they should be carefully managed to maintain optimal nutrient retention during the composting process (Jusoh et al., 2013).

Nutrient analysis further revealed that IMO inoculation enhanced both macro and micronutrient concentrations in the final compost. Treatments containing IMO exhibited higher levels of nitrogen (N), phosphorus (P), and potassium (K), as well as calcium (Ca) and magnesium (Mg). These increases are likely due to the ability of indigenous microorganisms to solubilize, mobilize, and mineralize nutrients trapped in the composting materials, improving their bioavailability (Dai et al., 2023; Ren et al., 2022). Aeration through regular turning also

improved the mean NPK content ($P < 0.05$) compared to unturned piles, indicating that oxygen supply enhances microbial enzyme activity and nutrient release efficiency. The improvement in both macro and micronutrient content highlights the potential of IMO technology not only for waste reduction but also for nutrient recycling, reducing dependence on synthetic fertilizers and minimizing agricultural pollution.

The moisture content of the compost at maturity was another parameter significantly influenced by IMO application. Moisture plays a pivotal role in maintaining microbial activity and ensuring continuous decomposition. The presence of IMO enhanced the structural integrity of compost, which improved its moisture retention capacity. Turned piles recorded higher moisture content than unturned ones, possibly due to the cooling effect of aeration, which reduced excessive evaporation. Similar observations have been reported by Khalib et al. (2019) and Xie et al. (2024), who found that the integration of beneficial microorganisms improved organic metabolism and compost structure, leading to higher water-holding capacity. This aligns with Kashi et al. (2021), who observed that microbial inoculants such as *Pseudomonas putida* enhanced compost moisture retention. These findings reinforce the idea that indigenous microorganisms play a critical role in optimizing compost quality through moisture stabilization and improved texture.

Variations in the C/N ratio among treatments also revealed the distinct decomposition efficiencies between coffee and rice husks. The elevated C/N ratio in the rice husk compost was due to the high carbon, lignin, and cellulose

content in rice husks (Iqbal et al., 2019). In contrast, coffee husks, with less lignin and more accessible nitrogen, supported faster microbial activity and a greater reduction in C/N ratio over time. Maintaining an optimal C/N ratio is therefore essential for sustaining microbial diversity and ensuring efficient composting (Huhe et al., 2017). Moreover, composts with higher C/N ratios, such as those from rice husk mixtures, can still enhance soil structure, water retention, and fertility by contributing more carbon for humus formation (Pereira et al., 2016; Tiquia, 2010).

Overall, the composts produced using IMO were of high quality, exhibiting an earthy smell, dark color, and smooth texture key indicators of mature compost. The inferior texture and occasional odor in rice husk-based composts can be linked to their lower nitrogen content, which limits microbial decomposition compared to coffee husks. Collectively, the results demonstrate that IMO significantly improves the composting process by accelerating decomposition, optimizing temperature and pH, enhancing nutrient content, and improving moisture retention. These outcomes confirm the potential of indigenous microorganisms to transform agricultural waste into nutrient-rich biofertilizers that promote soil health, reduce reliance on chemical fertilizers, and support sustainable agricultural systems.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This study evaluated the potential of indigenous microorganisms (IMOs) in converting coffee and rice crop residues into nutrient-rich biofertilizer. The general objective was to assess the efficiency of IMOs in decomposing coffee and rice husks when combined with goat manure. Specific objectives included determining the decomposition rate, assessing the quality of the resulting biofertilizer, and monitoring parameters such as pH, nutrient content, temperature, moisture retention, and carbon-to-nitrogen (C/N) ratio throughout the composting process. Results indicated that IMO application significantly increased compost pile temperatures, enhancing microbial activity and accelerating organic matter decomposition. Compost pH was positively influenced, with most treatments reaching near-neutral values suitable for crop growth. Treatments inoculated with IMOs also exhibited higher organic matter content and improved macro- and micronutrient levels. Moisture retention was consistently better in IMO-treated piles, and the C/N ratio declined over time, reflecting efficient microbial activity. Overall, the findings demonstrate that IMOs can optimize composting processes, producing high-quality, nutrient-rich biofertilizers from agricultural waste and providing a sustainable strategy for soil fertility improvement.

5.2 Conclusion

The findings of this study demonstrate that indigenous microorganisms significantly contribute to the efficient breakdown of coffee and rice husk waste into biofertilizer. The application of IMO not only increased compost temperatures and microbial activity but also contributed to improved pH, moisture retention, and nutrient availability in the compost. The findings support the hypothesis that IMO can accelerate the decomposition process and enhance the quality of the resulting bio fertilizers, making them beneficial for agricultural practices. Furthermore, the study demonstrated that utilizing agricultural waste products like coffee and rice husks along with IMO can lead to sustainable waste management solutions while reducing reliance on synthetic fertilizers.

5.3 Recommendations

Based on the study findings, the following recommendations are made:

1. Adoption of Indigenous Microorganisms (IMOs) for Agricultural Waste Decomposition

The use of IMOs is strongly recommended for the composting of agricultural residues especially coffee husks, which showed a faster decomposition rate compared to rice husks. The accelerated breakdown was evidenced by a sharper decline in the C/N ratio and higher temperature peaks within a shorter period (averaging 45–51°C during the thermophilic phase). This indicates that IMOs significantly increased the rate of decomposition and microbial activity compared to non-IMO treatments

2. **Effectiveness of IMOs Over Conventional Composting**

Treatments with IMOs produced composts with higher organic matter content, improved pH (near-neutral), and enriched macro nutrient concentrations (notably N, P, and K) compared to those without IMOs. These results demonstrate that IMOs are more effective than conventional composting methods in both the speed and quality of biofertilizer produced. It is therefore recommended that farmers and waste management practitioners adopt IMO-based composting as a sustainable, low-cost alternative to synthetic fertilizers and traditional composting techniques.

3. **Socio-Economic Evaluation of IMO Technology**

Beyond technical performance, future research should assess the socio-economic implications of adopting IMO technology among smallholder farmers. This includes analyzing cost-benefit ratios, labor requirements, accessibility of IMO materials, and farmers' willingness to adopt the technology. Understanding these factors will help guide policy formulation and scaling strategies for sustainable agricultural waste management and soil fertility improvement.

4. **Promotion of Farmer Training and Capacity Building**

Extension programs should incorporate training on IMO preparation, compost management, and application techniques to enhance adoption. Demonstration plots and farmer field schools could play a key role in disseminating the technology, improving awareness of its agronomic and environmental benefits.

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APPENDICES

Appendix 1: Influence of turning and not turning during composting on the chemical characters of compost at maturity

Sample size tested was 8 except for the pH which had 7 tested as a result of a sample having a zero measurement, this taken to be a neutral point and no sign can be assigned therefore the Wilcoxon sign rank excludes the zero measurement from the calculation.

Treatment	pH	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Organic matter (%)	Moisture content (%)
Turned	7.1	2.92	1.30	1.510	0.82	1.256	26.7875	26.79
Un-turned	7.42	2.16	0.82	1.14	0.45	0.86	23.88	23.89
P value	0.016	0.008	0.008	0.008	0.016	0.039	0.045	0.023
Sample size	7	8	8	8	8	8	8	8