UNIVERSITY OF EDUCATION –WINNEBA

FACULTY OF ENVIRONMENT AND HEALTH EDUCATION

MAMPONG-ASHANTI

ENHANCING FAECAL SLUDGE COMPOST QUALITY BY CO-COMPOSTING WITH RICE HUSK AS BINDING AGENT

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(MASTER OF PHILOSOPHY)

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DECLARATION

CANDIDATE’S DECLARATION

I, NICHOLAS KOJO NJADA, hereby declare that except references to other people’s works which have been duly acknowledged, this thesis is my original work towards the award of a Master of Philosophy and Environmental and Occupational Health Education and that this thesis or part has not been accepted for the award of a degree in this University or elsewhere.

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DEDICATION

This research work is dedicated to my mother, Mary Sanja Njada and landlady Akua Boatemaah for her prayers, love, and support in all aspects of my academic endeavor.

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ABSTRACT

Rice husk and feacal sludge poses waste management challenges, which result in Sanitation or environmental consequences in Ghana. Feacal sludge is rich in nitrogen (N) and phosphorus (P) while rice husk is rich in potassium (K) and organic carbon (OC). As such co-composting these two bio-wastes could be useful for applications in agriculture while minimizing the environmental consequences associated with the disposal of these wastes at landfills. This study aimed to enhance rice husk compost by co-composting with feacal sludge. The University of Skill Training and Entrepreneurial Development (AAMUSTED) Mampong campus was the place of study. A composting experiment was done by mixing Rice husk (R) and Faecal sludge (F) in the ratios: RF (1:0.5), RF (1:1), and RF (1:2) by volume in a complete randomized design. The aerobic composting method was used for the treatment and was turned weekly, to enhance decomposition. Results of the study showed that raw rice husk was low in total N (0.47%), P (0.05 %), Total Coliform (2.3 x10^3 CFUg^{-l}), and feacal coliform (nil CFUg^{-l}) compared to raw feacal sludge which was high in N (3.15 %), P(0.79 %), Tot. coliform (2.4x10^{17} CFUg^{-l}) and feacal coliform (4.2 x10^{13} CFUg^{-l}) . The OC (45.03%) content, C: N ratio (95), and K (1.26%) of rice husk were very high unlike that of feacal-sludge: OC (32.66%), C: N (10.36) and K (0.81%). At the end of the composting experiment, RF (1:2) recorded the highest total N (21000 mg/kg) and P (9300 mg/kg) followed by RF (1:1) (16000 N mg/kg; 6800 P mg/kg) and RF (1:0.5) (1400 N mg/kg; 4200 P mg/kg). On the contrary, the highest total K among the mixing ratios was recorded in RF (1:0.5) (10000 mg/kg) followed by RF (1:1) (9300) and RF (1:2) (7400). The highest mineralized NPK was observed in RF (1:2)(2900 N mg/kg; 1581 P mg/kg; 2072 K mg/kg) followed by RF(1:1)(2400 N mg/kg; 680 P mg/kg; 1581 K mg/kg) and RF(1:0.5)(1260 N mg/kg; 210 P mg/kg; 1400 K mg/kg). Concerning pathogen load, RF (1:2) recorded the highest total and feacal coliform (7.38 in log units; 6.38 in log units) followed by RF (1:1) (6.63 total coliform in log units; 5.32 feacal in log units) and the least being RF (1:0.5) (4.38 total coliform in log units; 3.63 feacal coliform in log units). RF (1:2) was identified as the mixing ratio that gave the best compost among the co-composting treatments based on total NPK, mineralized NPK, and other nominal factors at the end of the co-compost experiment. It was therefore recommended that Rice husk be co-composted with feacal sludge in a ratio of 1:2.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Due to the increase in the world's population, there is increased demand for food and this has resulted in the production of large amounts of agricultural wastes (Peng *et al.*, 2023). One of these agricultural wastes is rice husk, a by-product of the rice milling industry. Rice husk (RH) is waste generated from the agriculture industry. They are abundant at the farms and the processing unit within the municipality (Hisham and Ramli, 2019). Globally, the production of (RH) is approximately 150 million tons per annum (Madin *et al.,* 2023). Rice production in Ghana has increased from 0.09 and 0.16 million hectares while yields fluctuated between 1.7 and 2.7 tonnes per hectare (Abebrese *et al.*, 2023). However, it appears that from 2007, rice production has been on the increase with 2010 production levels being more than double 2007 levels (from 185,300 tonnes in 2007 to 491,600 tonnes in 2010) with an average annual growth of more than 15 % over the period 2005-2010, despite the production drop experienced in 2007 (ISLAM, 2020).

The main rice-producing regions in Ghana, Northern, Volta, and Upper East regions, produced between 45,000 – 60,000 tonnes per year each. The Northern region is the main producer with about 63000 tonnes in 2009 (Seglah *et al.*, 2022). In Ghana, for the year 2012, paddy rice harvested was 481 metric tons which produced milled rice of 332 metric tons (Abebrese *et al.*, 2023). The problem with rice husks is with the management (Latifah *et al.,* 2015). Ghana as a developing country is no exception to this predicament regarding rice husk management. Rice producing areas like Kpong Irrigation Project (KIP) in the Asutsuare catchment area after the rice are harvested, the rice straw is left in the field; rice bran is sold to pig and poultry farmers. The rice husk is left at the surrounding of milling machines which pile up and later burnt to reduce their volume (Murimi and Gbedemah, 2018). The burning process of RH produces a lot of smoke which is detrimental to human health and the environment but under controlled temperature will produce a waste product known as rice husk Ash (RHA) and this has both health and environmental benefits (Hanuni Ramli, 2019). A solution to reducing this problem could be an approach of bio-based circular economy; a circular economy is a regenerative system focusing on maximizing the reuse of resources and bio-wastes (Venkatesh, 2022). In a bio-based economy, bio-waste is not landfilled. Instead, this approach promotes the valorization of wastes into valuable products such as biogas, biofuel, and bioplastics among others using novel processes and technologies; accordingly, the call for a bio-based, circular economy is getting louder and louder as a measure for a more sustainable economy (Venkata *et al.,* 2018). The use of composted rice husk in agriculture is therefore an interesting way to achieve both the disposal of this waste matrix and the supply of organic matter (OM) to soils (Ashokkumar *et al.,* 2022).

Rice husk (RH) contains a high C: N ratio of about 85:1 and is rich in silica and lignin which makes it difficult to degrade (Freitas *et al.,* 2023) and thus cannot be used directly in agricultural practices since it is hardly decomposed and disintegrated in soil (Demir & Gülser, 2021). Therefore, raw husk is subjected to composting to reduce the C/N ratio, but it can still stay in the soil for a long time as compared to other organic wastes (Aziz *et al.,* 2022). Since rice husk compost can remain in the soil for a long time without decomposition, improving the effects of composted rice husk on the soil water regime can then be monitored for longer periods (Omar *et al.,* 2021). Compositing can offer an efficient postharvest tool for recycling rice husks (Geetha *et al.,* 2022).

Composted material can be used to improve the physicochemical characteristics of agricultural lands and to ensure soil fertility (Dang *et al.*, 2022). Combination with sludge has been reported to aid RH decomposition (Zhang *et al.*, 2022). Feacal sludge is slurry or semisolid, results from the collection, storage, or treatment of combinations of excreta and blackwater (i.e. toilet wastewater) from onsite sanitation technologies (Jain *et al.,* 2022: Samal *et al.,* 2022). Generally, when feacal sludge (FS) is collected from on-site sanitation installations, the sludge would need to be treated before disposal (Samal *et al.,* 2022).

However, common practice in many developing countries is to transport FS from tanks directly to dump sites or to dispose of it in the vicinity into dug pits, drainage systems, and water bodies without treatment. (Liu *et al.*, 2023). Feacal matter management which is equally a big challenge in Ghana is rich in microbes and nutrients which could be co-composted with the rice husk for applications in agriculture thereby closing the nutrient loop (Greff *et al.,* 2022). The composting process also reduces the mass and volume of organic materials through microbial degradation of organic matter and C in the form of CO_2 (Kauser & Khwairakpam, 2022; Yang *et al.,* 2019; Wu *et al.,* 2019).

1.2 Problem Statement

The increasing population in Africa has led to an increased generation of bio-waste, which comprises 60 % of the total waste (Emenike *et al.*, 2013). Typically, sewage sludge produced is around 40–60g dry matter per resident per day for both urban sewage plants and industrial sewage plants and it is expected to raise higher (Ahmed *et al.,* 2023). Treatment plants in Ghana generally produce sludge of about 350–900 m^3/day of wet sludge depending on the size of the treatment plant (Ahmed *et al.,* 2023).

The inappropriate disposal of feacal matter and RH is a major challenge and environmental concern in developing countries. According to the Food and Agriculture Organization (FAO), agricultural wastes form a significant portion of the bio-waste due to increased demand for food. Rice husk, a by-product of the rice milling industry is one of the agricultural wastes that is rising in Ghana, posing management challenges, and leading to environmental pollution (Loiko et al., 2022). Burning of rice husks disposed at the landfill usually generates ash (Pode, 2016) as well as smoke (CO_2). The ash is washed into water bodies during rainfall events causing water pollution while the CO_2 emanating from the burning contributes to global warming. In another development, feacal matter disposal equally poses a threat to the environment (Cofie *et al.*, 2009). Disposal of feacal sludge at landfills can result in increased nutrients (P and N) and pathogen concentrations in surface freshwaters and estuaries in Ghana via runoff. The nutrient load in water bodies enhances the growth of algae (eutrophication), which affects aquatic ecosystems, as well as water quality for human use. Higher nutrients (N and P) and pathogen contents in water bodies cause human health problems. A lot of efforts have been put into the treatment of sanitary waste, however, much has not been done to recycle these wastes for reuse, especially, on feacal sludge in connection to rice husk (Loiko *et al.,* 2022). Even though there has been some work done on the treatment and disposal of feacal sludge and the co-composting by combination of the two (feacal sludge and rice husk) (Coffie *et al* 2016; Nartey *et al* 2017) however, further study was needed to inform policies and decision making.

1.3 Justification

Over the years, there have been several ideas for the development of various technological alternatives aimed at improving the sanitation system through the recycling of organic solid wastes (Tsui & Wong, 2019). Co-composting is one of the ideal ways of managing organic waste (Majbar *et al.,* 2018). In the case of human waste and rice husk, the co-compost is ideal, because the two materials complement each other. Human waste is high in nitrogen content and moisture and the rice husk is high in carbon content and has good bulking quality (Gallizzi, 2018). Although rice husk has a high C/N ratio and low nutrient content, it is characterized by a waxed surface and high silica contents which reduce water-holding capacity and could limit microbial attack (Younis *et al.,* 2022). Mitigating environmental problems from these bio-wastes is the key focus and also obtains economic value through the conversion of the bio-wastes into innovative organic fertilizer resources which can be safely returned to the soil (Mushtaq and Khalid, 2019). In Ghana, recently, composting and co-composting have always focused on the use of municipal waste and the use of sawdust from the sawmill factories. However, there are other means of co-composting which involves different materials other than the municipal wastes and sawdust from the factories. Co- composting feacal sludge with Agricultural wastes such as oil palm empty fruit bunches and cocoa pod husks, have been studied (Gbenatey *et al.,* 2017). Even though there has been some work done on the treatment and disposal of feacal sludge and the co-composting by combination of the two (feacal sludge and rice husk) (Coffie *et al* 2016; Nartey *et al* 2017). Determine the mixing ratio that gives the highest NPK content and least bacterial load among the co-composting treatments. As well as, determine the available nutrients for plant of rice husk and feacal sludge co-compost is must study. The rationale for this research is to fill the data gaps about the use of feacal sludge and rice husk that limit scientific decision-making and implementation.

1.4 Objectives

1.4.1 Main objective

The main objective was to enhancing faecal sludge compost quality by co-composting with rice husk as binding agent.

1.4.2 Specific objectives

The specific objectives were to:

1. Determine the physico-chemical properties and bacterial load characterization of feacal sludge and rice husk.
2. Determine the mixing ratio that gives the highest NPK content and least bacterial load among the co-composting treatments.
3. Determine the available nutrients for plant of rice husk and feacal sludge co-compost.

1.5 Research questions

The study was guided by the following questions;

1. What are the physioco-chemical properties and bacterial load of faecal sludge and rice husk?
2. What are the physioco-chemical properties and bacterial load of faecal sludge and rice husk co-composting?
3. What mixing ratio of rice husk and faecal sludge co-compost formulation gives the highest NPK and lowest bacterial load?

1.6 Significance of the Study

This study sought to establish the rice husk compost by co-composting with faecal sludge. Since not much or very little research has been done concerning the topic in and outside Ghana, the study will serve as an insight that will reveal physioco-chemical properties and bacterial load of faecal sludge and rice husk, an optimum mixing ratio of faecal sludge and rice husk co-composting and optimum mixing ratio of rice husk and faecal sludge by increasing the faecal sludge content. The results from this are expected to contribute immensely to a better understanding of the issue with regards to rice husk compost with feacal sludge and the findings will serve as a channel for improvement and proper management of both rice husk and feacal sludge. The findings of this study will serve as a basis for offering purposeful suggestions to stakeholders in waste management and also be useful in improving compost. Another significance of the study is that the findings can be used to examine the relationship between faecal sludge's ability to decompose rice husks. Additionally, the study will serve as resource material for students/researchers who may make a related study in the future.

1.7 Limitations and Delimitations of the Study

The study will be centered in Mampong Municipal as all materials were taken within the municipality. The focus of the study is on enhancing rice husk compost by co-composting with faecal sludge. A review of the literature will consist of compost, types of compost, factors affecting compost, rice husk, characteristics of feacal sludge, and many others. Limited time and financial constraints were a limiting factor. Despite these limitations, analyses from the data that were obtainable were sufficient to provide meaningful conclusions to the research questions.

1.8 Organization of the report

Chapter one introduces the study and provides the outline of the study which is to investigate the utilization of rice husk compost with faecal sludge for agricultural purposes. It also captures the background information, problem statement, objective of the study, research questions, significance of the study, scope of the research, limitations, and delimitations of the study. Chapter two deals with the review of literature related to the subject of study. The review involves in-depth studies related to the problem under study.

The third chapter describes the methodology used in the study. The analysis and results are presented in chapter four. The fifth chapter captures the interpretation of all content analysis of the data collected in the field of study. In chapter six, the main focus is the summary, conclusions, and recommendations. This chapter provides a summary of all the chapters in the study. In addition, the chapter also made a few recommendations on alternative development approaches before concluding the study.

CHAPTER TWO

LITERATURE REWIEW

2.1 Composting

Composting involves the breakdown of biodegradable organic matter by microorganisms under controlled conditions, in which the organic material undergoes a high-temperature stage that allows sanitization of the waste by elimination of pathogenic microorganisms (Dang & Le, 2021: Mengistu *et al.,* 2017). Composting is less in terms of technological investment that can transform organic waste into useful organic matter through bio-oxidation which improves the quality of soil for plant growth by controlling aeration, water status, and micro- and macronutrients (Mushtaq and Khalid, 2019).

2.2 Types of Composting

There are three basic types of composting – anaerobic, aerobic, and vermicomposting.

2.2.1 Anaerobic composting

An anaerobic composting is the breakdown of biodegradable organic matter by reduction in the absence of oxygen where end products such as methane (CH_4) and hydrogen sulfide (H_2S) are released (Andriani *et al.,* 2020: Gutierrez *et al.,* 2022). Anaerobic decomposition of organic matter is, however, often associated with the formation of foul-smelling gasses such as indol and skatol (Andraskar *et al.,* 2021). This method of composting involves little or no work, however, the maturation of the pile is usually prolonged and the process does not generate enough heat to safely kill pathogens and weed seeds (Michel *et al.,* 2022). The process usually takes place at temperatures between 80^oC and 450^oC, with mesophilic microorganisms breaking down the soluble and readily degradable compounds (Mehta and Sirari, 2018).

2.2.2 Vermi-Composting

Vermicomposting refers to the composting of organic material using red worms (Zhou *et al.,* 2022). These specialized worms thrive by getting their weight in organic material daily (Thakur *et al.,* 2021). The material that passes through the worms' bodies is called "castings” and can contain five times more nitrogen, seven times more phosphorus, and eleven times more potassium than ordinary soil (Thakur *et al.,* 2021). These worms require special care to work effectively (CREMENEAC and CARAMAN, 2022). They work between temperatures of 16 ℃ and 25 ℃, and are sensitive to light (Zhang *et al.,* 2020).

2.2.3 Aerobic composting

Aerobic composting is defined as the process in which, under suitable environmental conditions, facultative aerobic organisms, principally, thermophilic, utilize considerable amounts of oxygen in decomposing organic matter into fairly stable humus material (Oshins *et al.,* 2022). As the quickest way to produce high-quality compost, aerobic composting is the widely accepted means of stabilizing organic wastes and converting them to a usable, and value-added compost product (Mahapatra *et al.,* 2022). In this process, higher temperatures (above 60℃) can be reached and both mesophilic and thermophilic micro-organisms are involved in the composting process (Pan *et al.,* 2022). Research has pointed out that this process of aerated thermophilic composting can provide a high degree of pathogen inactivation. It produces a well-composted material which is a useful and effective soil conditioner (Nenciu *et al.,* 2022).

2.3 Composting processes

There are three general elements of a composting process:

1. Pre-processing: This can include grinding or shredding and separation of solid inorganic waste (Amrul *et al.,* 2022: Zhang *et al.,* 2019). In the case of co-composting, this pre-processing ends with the addition of sludge to other organic waste/material (Amrul *et al.,* 2022: Vasanthy *et al.,* 2022).
2. Composting: This is done by windrows, aerated static piles, or in-vessel composting (Michel *et al.,* 2022: Wilson, 2022).
3. Post-processing: This consists of grinding or sieving, de-stoning, and other steps to prepare the compost for utilization and marketing (Chandrasekara & Shahid, 2022: Maisarah *et al.,* 2018).

Some organic materials like feacal sludge, because of their nature (high moisture content, low carbon-nitrogen ratio, etc.) are usually composted with other organic materials (like sawdust) in co-composting (Ghangrekar, 2022).

2.4 Co-composting

Co-composting is considered one of the waste treatment methods in which different types of waste are treated (composted) together. Co-composting is an attractive and interesting example of an integrated waste management method of resource recovery and waste disposal (Ruffino and Cerutti, 2022). An example is the composting of feacal sludge and rice husk, this kind of composting is advantageous because the two waste materials well complement each other (Qadwe *et al.,* 2022), thus faecal sludge is high in nitrogen content and moisture and the rice husk is high in organic (carbon) content and has good bulking quality (Manga *et al.,* 2022). Furthermore, both of these waste materials can be converted into useful products, and proper mixing of the two ensures an optimum carbon-nitrogen ratio to enhance the biodegradation process (Liu *et al.,* 2023).

2.5 Factors Affecting Composting

Compost maturity and stability are important factors during the composting process (Chen *et al.,* 2022). For achieving compost maturity, environmental factors such as temperature, moisture content, pH, and aeration should be appropriately controlled, and parameters such as carbon-nitrogen ratio, particle size, and nutrient content are also important factors affecting compost quality (Ayilara *et al.*, 2020).

2.5.1 Temperature

The composting process can be divided into four major microbiologically important phases based on temperature. These phases may have considerable overlap based on temperature gradients and differential temperature effects on microorganisms

These are

(i) the mesophilic phase;

(ii) the thermophilic phase;

(iii) the cooling phase; and

(iv) the maturation phase (Lin *et al.,* 2018).

The composting process is initiated by the microbiological decomposition of organic material at the mesophilic temperature range (optimum growth temperature range = 20-45 °C) multiplying quickly on the readily available sugars and proteins. They generate heat through their metabolism and raise the temperature to a point where their activities become suppressed. Upon active respiration, the temperature within the pile increases to a level that is prohibitive to mesophiles but suitable for thermophiles (Lin *et al.,* 2018). This shift is also associated with a decrease in species diversity. The dominant bacteria of the thermophilic phase are spore formers (Bacillus spp.), and thermophilic fungi have also been found (Lin *et al.*, 2018). Then a few thermophilic fungi and several thermophilic bacteria (optimum growth temperature range = 50-70 °C or more) continue the process, raising the temperature of the material to 65 °C or higher. This peak heating phase is important for the quality of the compost as the heat kills pathogens and weed seeds. Microbial activity slows down as nutrient sources deplete, causing a decrease in temperature and the beginning of the curing phase, which consists of the cooling and maturation phases. The temperature during the cooling phase is similar to the mesophilic phase or low, and mesophilic organisms thrive during this stage (Lin *et al.*, 2022).

Generally, temperature is one of the most important variables in the composting process (Sokač *et al.,* 2022). To enhance the removal of non-spore-forming pathogens, for example, Salmonella and E. coli, it is recommended that in a composting process, the temperature must exceed 55 °C for at least two weeks (Subirats & Topp, 2022). A temperature rise during composting is caused by the oxidation of organic matter (Gao, 2022). The level of temperature rise depends on the rate of metabolic activity, the extent of oxidation, and the rate of heat transfer from the composting material (Finore *et al.,* 2023).

2.5.2 Oxygen (Aeration)

Composting is primarily the biological oxidation of organic waste material of recent origin via microbial metabolism to a stabilized organic residue (Ma *et al.*, 2022). Most of the organisms that decompose organic matter are aerobic - they need air to survive. The process is associated with the production of heat, microbial biomass, carbon dioxide, and water. It is desired that the composting process be based on aerobic decomposition, and thus the availability of oxygen in the compost heap is of prime importance (Sánchez-García *et al.*, 2015). The functions of Aeration in composting are;

(i) Support of aerobic metabolism
(ii) control of temperature; and
(iii) removal of moisture as well as carbon dioxide and other gases.

Insufficient aeration promotes the formation of anaerobic zones and the generation of foul odour, whereas excessive aeration limits microbial activity as a result of the reduced moisture and associated cooling Proper air circulation is obtained by maintaining aerobic conditions under 10–15% Oxygen (United Nations University Institute for Integrated Management of Material Fluxes and Resources (UNU-FLORES), 2018). The oxygen content in the circulating air should not fall below 18% in windrows, although there are few experimental data to support this value. The principal aeration methods providing oxygen during composting are physical turning of the mass, natural convection, and forced aeration (Oshins *et al.*, 2022). The optimal turning frequency however varies significantly depending on the type of initial composting material used (El-mrini *et al.*, 2022).

2.5.3 Moisture Content

The moisture content of the composting pile is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (Singh *et al.*, 2023). Very low moisture content values would cause early dehydration during composting, which will arrest the biological process, thus giving physically stable but biologically unstable composts (Kiran *et al.*, 2022). On the other hand, high moisture may create anaerobic conditions through water logging, which will prevent and halt the ongoing composting activities (Ravindran *et al.*, 2022). Most materials are best composted with a moisture content from 50% to 70%, and some other materials can be effectively composted beyond this range (about 25–80% on a wet basis) (Amuah *et al.*, 2022). The moisture content of compost varies depending on the porosity of the reactor feed, free air space, aeration, temperature, and other related physical factors (Oshins *et al.,* 2022). Moisture in this context is defined as weight loss after the sample has been dried to constant weight at 105 °C for 24 hours. Bacterial metabolic activity is severely inhibited when the moisture content drops below 40% (Chen *et al.*, 2022). If anaerobic composting is practiced, the maximum moisture content is not as important, since oxygen maintenance is not a factor (Fatima *et al.*, 2022). Also if the composting procedure has initial aerobic conditions to produce high temperatures lasting a few days for the destruction of pathogenic organisms, followed by anaerobic composting, the optimum moisture content for maximum oxygen consumption rates has been described between 50 and 70% depending on the character of the composting materials *(Amuah et al.*, 2022; Fatima *et al.*, 2022).

2.5.4 pH

The optimal pH range for most biological reactions in composting is between 5.5 and 8.0 standard pH Units (Ho *et al.*, 2022). Bacteria work best at near-neutral pH, whereas fungi favor an acidic pH range. At high pH, ammonia gas may be generated and this may cause adverse odor, microbial population decline, and poor-quality compost product (Ma *et al.*, 2022). The effects of extreme pH on the composting process are directly related to the effect of pH on microbial activity or, more specifically, on microbial enzymes (Ge *et al.*, 2022). The pH-buffering capacity increases as a result of humus formation. Liu *et al.* (2022) reported that the addition of 5% rock phosphate to pig manure and rice straw compost decreased the availability of Cu and Zn related to the increase of the compost pH value organic carbon stabilization.

2.5.5 Carbon-Nitrogen Ratio (C/N)

The process of decomposition of organic matter is affected by the presence of carbon and nitrogen. The carbon-nitrogen ratio represents the relative proportion of the two elements (Alekseev & Abakumov) The optimal carbon-nitrogen ratios for the microbiological decomposition of organic material in composting processes have been reported to be in the range of 25-30 (Lin *et al.,* 2022). In other words, the ingredients placed in the pile should contain 25 to 30 parts carbon to 1 part nitrogen. In general, this range of carbon-nitrogen ratio is similar to that reported for agricultural soils (Li *et al.,* 2022). If the C/N ratio is low, as is the case for night soil, the microbiological degradation leads to excess ammonia formation, which increases the pH and thereby enhances ammonia volatilization (Xie and Zhou, 2022). Conversely, if the carbon-nitrogen ratio is too high, the process becomes nitrogen limited. Too much carbon will cause the pile to break down too slowly, while too much nitrogen can cause odour (Shadab, 2022).

The carbon provides energy for the microbes and also combines with nitrogen in building cell protoplasm. Therefore, more carbon is needed than nitrogen. Besides limiting the growth and amount of biomass, nitrogen limitation may lead to an extensive organic acid formation from carbonaceous waste, which would tend to lower the pH and thereby retard microbial activity (Mariuzza *et al.,* 2022). The C/N ratio is not constant during composting because of the removal of carbon as carbon dioxide upon microbial respiration. Most materials added to compost tend to be rather rich in C, and so the C/N ratio of the resulting compost is often too high which slows down the process (UNU-FLORES, 2018).

2.5.6 Particle Size Decomposition

Different types of bulking materials have been used during the composting process. Common bulking materials are fibrous carbonaceous materials with low moisture content (Quadar *et al.,* 2023). These usually are dry materials and help keep the compost aerated. The many types of bulking materials include sawdust, wood shavings, rice husk, coconut fruit fiber, maize cob, dried grass, hay or straw, organic solid waste, and many more. Bulking materials often used in composting operations include sawdust, straw, peat, rice hulls, cotton gin trash, manure, refuse fractions, yard wastes, wood chips, and a variety of other wastes (Rynk *et al.,* 2022). Feacal (sewage) sludge, industrial wastes (e.g., food, pulp, and paper), yard and garden wastes, municipal solid wastes (up to 70% organic matter by weight), soft pruning, clippings and leaves, kitchen waste like fruit peelings, eggshell and paper shredded, mixed with grass cuttings and used sparingly as materials that can be composted (Oshins *et al.,* 2022).

Inorganic materials such as lime or ash can be added to feacal sludge to raise their pH to improve composting (Samal *et al.,* 2022). Relatively smaller particles of bulking materials have more surface area for soil organisms to work on. In general, the smaller the particle size, the faster the raw materials will be transformed into compost (Lu *et al.,* 2022). To speed up the composting process, one should grind, cut, chop, or smash the raw materials to reduce the particle size. Similarly, the positive effects of biochar on compost maturation and greenhouse gas emissions can be attributed mainly to its porosity, which creates additional biological space and is also a function of its particle size distribution (Osman *et al.,* 2022) in the composting mass.

2.6 Organisms in Composting

Microorganisms such as bacteria, fungi, and actinomycetes which are the preferred microorganisms account for most of the decomposition, as well as the temperature rise that occurs in the composting process (Ho *et al.,* 2022). These microorganisms are preferred since they provide the most rapid and effective composting. Aerobic organisms thrive at oxygen levels greater than 5% (air is about 21% oxygen). During the process of aerobic digestion, aerobic bacteria will multiply in the presence of free oxygen. The aerobic treatment processes in the presence of air utilize those microorganisms also called aerobes (Magdalena *et al.,* 2022). The microorganisms predominantly bacteria breakdown feacal sludge under aerobic conditions in the presence of oxygen (Shukla *et al.,* 2022). In essence, the activity of microorganisms causes both an increase in temperature, hence the pathogen destruction, and a release of energy, CO_2, H_2O, NH_3, and other gases, while consuming oxygen (Huang *et al.,* 2022). During the process, both external and internal enzymes break down food (substrates) into readily usable forms to be used by the bacteria for the maintenance and propagation of life (Oshins *et al.,* 2022).

The energy produced is used by the bacteria for their reproduction. Bacteria increase at an exponential rate until there is a short supply of oxygen. The metabolism of the bacteria then slows down to a conventional rate and eventually becomes stationary when the oxygen supply is shortened (Kanong and Sakulrat, 2022). In this mode, sufficient substrate exists only to maintain life, not to promote growth (Wu *et al.,* 2022). A good composting process depends upon the activity of microorganisms and their metabolism which can be dramatically affected by the presence of toxic material in the faecal sludge (Samal *et al.,* 2022). Constituents such as organic and inorganic solvents and heavy metals can inhibit biological activity during the composting process (Dan *et al.,* 2023). In the case of organic contaminants, biochar might also stimulate the development of microorganisms that can degrade them (Xiang *et al.*, 2022).

2.7 Indicators of Compost Stability and Maturity

Compost stability and maturity are essential for its successful application, particularly in high-value horticultural situations (Liu *et al.*, 2022). Several other authors also claimed that the final quality depends on the nature of the raw material, the type of earthworm used, and the environmental conditions prevailing (Ganiger *et al.*, 2020). The composting process is normally taken to be complete when the active decomposition stage is over and the C/N ratio is around 20 (Hemati *et al.*, 2022). Maturity and stability indicators that have been used in other composting studies include C/N ratio, microbial activity, germination index, cation exchange capacity (CEC), humic substances, compost concentration of water-soluble carbon (WSC), dissolved organic matter, nitrate and nitrite, WSC/TN and WSC/organic-N (Meena *et al.*, 2019; Carlile *et al.*, 2019; Bhattacharjya *et al.*, 2019).

Table 2.1: Some of the recommended compost maturity indicator values

Parameter	Limit
C/N	<12
WSC	<1.7%
WSC/TN	< 0.7
WSC/organic-N	0.7
Nitrite	<0.16
Nitrate	<400
CEC	>60 meq /100g
germination index	>50%.

Sources : Mahapatra et al. 2022 ; Wan et al. 2022.

In some studies, compost maturity was estimated by measuring temperature and CO_2 emission from windrows (Peng *et al.*, 2019). A study by Ofei-Quartey *et al.* (2022), presented the potential and performance of combined treatment of faecal sludge (FS) and municipal solid waste (SW) through co-composting and reported a co-composting duration of 12 weeks (90 days) was indicated by the cress seed test, NO_3-N/NH_4-N and the C/N ratios to achieve a mature and stable product. Declining NH^+_4 and increasing NO_{-3} concentrations are indicative that a composting material has achieved maturity and is suitable for use. (He *et al.*, 2022), however, cautioned that no single maturity indicator can be applied to all composts because of differences in feedstock used. These maturation indicators will serve as a guide for this composting study.

According to the available literature, a composting period of 90-120 days (approximately 3-4 months) using the windrowing method has been shown to result in a mature co-compost product. Siriphan *et al.* (2017) found that this duration allowed for proper decomposition, reduction of pathogens, and improvement of physicochemical properties. Another study in India suggested a minimum composting period of 100-150 days (approximately 3-5 months) using windrows for rice husk and feacal sludge co-composting. Rathi *et al.* (2018) also found that this duration was sufficient for decomposition and pathogen reduction. In a study from Vietnam, researchers recommended a composting period of 120-180 days (approximately 4-6 months) using the windrowing method for rice husk and feacal sludge co-composting. Nguyen *et al.* (2019) found that this duration ensured sufficient decomposition and the production of a safe and nutrient-rich compost.

Some studies indicate that turning the windrows during the composting process can accelerate the maturation and stabilization of the co-compost. For example, Rathi *et al.* (2018) found that regular turning every 1-2 weeks helped to mix the materials, enhance aeration, and promote decomposition.

2.8 Compost Quality

Compost quality varies and depends on various factors like species of earthworm, raw material used, and age of compost (Rynk, *et al.,* 2022). Many authors have stated that compost maturity, feedstock source, degree of organic waste decomposition, physico-chemical and biological properties of compost, brewing time, and addition of microbial and nutrient supplements all affect the compost and compost tea's disease suppressive ability (Maturi & Kalamdhad, 2022; Mengesha *et al.,* 2017; Supriatna *et al.,* 2022). Compost quality is measured by several criteria, including moisture content, nutrient content, heavy metal, stability, particle size distribution, pathogen levels, and product consistency over time (Stehouwer *et al.,* 2022).

The presence of pathogens and the content of heavy metals are limitations in using sludge compost for agricultural purposes (Sude *et al.,* 2023). Feacal sludge usually contains harmful microbes, heavy metals, and toxic organic matter that if applied in agricultural lands can cause dangerous conditions for humans, animals, and plants (Samal *et al.,* 2022), thus, the sanitization of compost is essential. Heavy metal content has been detected in the compost made from these sludges (Xu *et al.,* 2022; Dar *et al.,* 2023), and guidelines and regulations regarding the application of the compost to farmland have been introduced in many countries (Awasth *et al.,* 2022). A study on the evaluation of microbiological and chemical parameters during wastewater sludge and sawdust co-composting revealed that microbial parameters such as total and faecal coliforms and *Salmonella* decreased significantly at the end of the composting period and covered A class standards of EPA for its application in agricultural lands (Ravindran *et al.,* 2022). Also in the final compost, no *Ascaris* ova was observed. In a study conducted by Mena *et al.* (2003), the composting process provided an acceptable degree of bioremediation for sanitizing products such as sewage sludge from municipal water treatment plants. In an experiment conducted during composting of source-separated human faeces using an insulated reactor, *E. coli,* and total coliforms were reduced to below detection in composts that maintained sanitizing temperatures for at least six days (Kelova *et al.,* 2021). A study conducted by Okoh (2023), observed well-sanitized compost as a result of high temperatures during cocomposting of faecal sludge and organic waste for agriculture.

2.9 Importance of Composting and Compost

Composting is the regulated decomposition of organic matter to produce a final product called compost; it is used in waste management as a method to recover organic waste (Ayilara *et al.,* 2020). Many studies have shown that the application of compost has promoted positive effects on a wide variety of crop. Recently, in a two-year experiment using digested SS compost applied to soil for grass forage and feed corn, Fei *et al.* (2019) demonstrated that effectiveness of compost on corn yield was similar to that of chemical N fertiliser. Furthermore, compost application to agricultural soil has been reported to improve the physical, chemical and biological and properties of soil (Boutasknit *et al.,* 2020). The improvement of total porosity caused by sludges and composts was comparable to that of manure in a two-year experiment on Italian sandy loam soil. Likewise, Mondal *et al.* (2015) observed the changes in soil quality in response to short-term application of municipal SS in a typic haplustept under cowpea-wheat cropping system. The results showed that the addition of compost at an application rate of 15 tons ha-1 to the upper layer of soil favors the amount of soil macro aggregate and porosity. The application of compost to agricultural soil has been shown to reduce the number of parasitic nematodes and increase both the numbers of micro-arthropods and earthworms (Karimi *et al.,* 2020). In addition, Lei et al. (2022) showed a clear increase in microbial biomass and enzymatic activities in the fourth year of compost application to clay soils.

2.9.1 Reduction of solid waste

The rapid increase in Municipal Solid Waste (MSW) generation during the 1980s and 1990s has motivated government agencies to focus on waste reduction and recycling (Mandal, 2019). The Year 2010 was the first recorded instance where there was a reduction in total MSW generation since the 1960s in the US. With an ever-increasing population, a reduction in total MSW generation would be difficult to maintain as residential waste accounts for 55 to 65 percent of total MSW generation (Banerjee and Sarkhel, 2020). Reducing the amount of landfilled waste will increase the life of landfills and reduce the loss of renewable resources. Composting of mixed organics, grass, and food scraps decreases the number of greenhouse gasses released into the global environment when compared to waste disposal in landfills contribute to, however, it increases the number of greenhouse gasses released for leaves and branches (Gautam, 2021). Composting of MSW is being investigated by numerous private companies and researchers for more efficient procedures, accelerants, and amendments to ensure the quality and viability of MSW compost (Guo *et al.,* 2019; Tundup *et al.,* 2021). Most current large-scale composting practices generally involve only green waste and a small portion of food waste from the MSW stream (Nguyen *et al.,* 2020). For example, the Salt Lake Valley, UT, landfill composting system involves mostly green waste, wood chips, and some food waste; the piles are rarely turned or aerated; and it requires approximately 6 months to produce a stabilized compost product. Testing is generally performed on finished products for organic carbon, phosphorus, nitrogen, and metal toxicity (Miranda *et al.*, 2021). The quality of compost produced from MSW depends on many sources of variation including composting facility design, control parameters, length of maturation, and the source of the waste (Cesaro *et al.*, 2019).

Inorganic fertilizers are required by law to declare the nitrogen, phosphorus, and potassium content, however, there is no required declaration for the content of compost, which contains various nutrients and organic matter, concerning its quality or potential toxicity (Su *et al.*, 2022). Sude *et al.* (2023) developed a method for assigning quality indices to grade compost quality based on: (1) a fertilizing value, and (2) the environmental threats due to its metal content. Metal-contaminated compost has been shown to significantly increase metal concentrations in compost-amended soils and results in a general increase in plant uptake of metals with primary accumulation in the root tissue (Liu *et al.*, 2019).

2.9.2 Degradation of Pesticides and Heavy Metals

The heavy metals commonly regulated are arsenic, cadmium, chromium, copper, lead, nickel, mercury, and zinc. Heavy metal content is a subject of concern for agricultural usage of compost, particularly the bioavailability of heavy metals in soils over long-term usage (Zheng *et al.*, 2022). Heavy metals occur naturally in places but are widely distributed through mining, manufacturing, and energy production. While compost can break down complex pesticide molecules, it cannot perform similar wonders on heavy metals, all of which are elements, the simplest form of coherent matter, composed of atoms (Miguel, 2022). They can sometimes be transformed into different (even less toxic) forms of themselves, but they cannot be further broken down. The most that compost can do is to offer binding sites to which these metals can attach (Cui *et al.,* 2022). If firmly enough incorporated into a complex molecule, even heavy metals can be rendered harmless. This is one reason why it’s important to use only mature compost. In unfinished compost, compounds are still undergoing quite rapid change, so no bond can be considered firm. A molecule captured at one minute may be discarded the next.

The best chance for immobilizing heavy metals is to wait until the microbial storm has passed, the heap has cooled, and the compost has matured. Kizilkaya *et al.* (2021) claimed that there is a chance of heavy metals in compost whereas, in vermicompost, earthworms remove and accumulate them in their bodies. Earthworms can remove excess metals and bioaccumulate them (El-Hassanin *et al.,* 2022). The earthworms not only turn the organic portion of hazardous waste into available nutrients (Liew *et al.,* 2022) but also reduce or remove heavy metals from wastes by accumulating them in their bodies during the vermicomposting process (Sun & Yu, 2023).

2.9.3 Improvement of Soil Fertility and Characteristics

Repeated application of compost materials to agricultural lands has been recognized as a reliable way to improve the physical and chemical properties of most soils, especially soils with poor structure, and low levels of soil organic matter (Bamdad *et al.,* 2022). Documented changes in physical properties include aggregate stability, porosity, bulk density, and soil water holding capacity. The primary positive effects of compost use on soil physical properties were discussed in a recent review by Osman *et al.,* 2022. They concluded compost use on land could potentially increase soil aggregate stability, water holding capacity, and plant available water by as much as 29 to 63% and 50% respectively.

Additionally, a decline in bulk density of 0.7 to 20% could be expected (Badaou and Sahin, 2022). The effect of compost application on soil hydraulic conductivity and infiltration varies with time, method, and rate of application (Castellini *et al.,* 2022).

There have been several reported benefits to the use of compost both as container media and as agricultural amendments. Material used in these trials has ranged from green waste compost, food waste compost, and composted biosolids from the wastewater treatment industry (Thomson *et al.,* 2022). Ozores-Hampton (2022) reported increased plant growth of flowering annuals and herbaceous perennials when biosolids compost was added at 50 – 100 % (vol) rates in a mix of biosolids compost, bark, peat and sand. There were no adverse effects of increasing compost additions on aeration, moisture retention, or bulk density. Tomato transplants grown in media containing yard trimming/biosolids compost had greater leaf area and shoot weight than those grown in peat/vermiculite media. They recommended that compost quality must be addressed before its usage in vegetable transplant media. The addition of food and wood waste compost to peat-based growth media at rates of 40 % (v/v) and 75 % (v/v) in some instances increased yields of Clematis plants compared to peat alone.

Some of the Clematis plants grown in compost-amended peat had higher nutrient contents than plants grown in peat-based growth medium alone. One of the conclusions of this report was that good quality compost could ‘substantially replace peat in container growth media’ due to (amongst other reasons) the increased plant growth and increased water-supplying capacity of these mixtures. Another consideration that must be made if compost is to be used as a container media growth medium is that the pore size should be small enough for handling but large enough to ensure a high porosity. The fine content is necessary to raise the CEC and moisture capacity of the final product. Also, if compost was to be packaged, they stated that the moisture content should be less than 40 %. The bulk densities of composted materials are much higher than peat-based growing media (approximately 3 times) which can have a significant impact on transport costs (Agarwal *et al.*, 2021).

Abdel-Razzak *et al*,. (2019) mixed compost samples with a commercial growing substrate and peat and assessed germination, plant growth, and nutrient effects on 3 plant species. Mixing compost with peat resulted in lower bulk density and higher porosity and water holding capacities along with lower salinities and electrical conductivities. Sánchez-Monedero *et al*., (2019) attributed a reduction in seed germination to the high electrical conductivity of compost samples. However, plant growth in mixtures containing compost could be enhanced depending on individual plant salt tolerances. This was due to high nutrient contents in compost-containing mixtures that coincided with high nutrient content in seedlings grown in compost mixtures. These authors concluded that compost could be used in vegetable transplant production; however, liquid feeding regimes at nurseries would need to be adjusted on a crop-by-crop basis.

Gebretsadikan *et al.*, (2022) showed that the beneficial yield effect gained by annual mulching of agricultural soil with composted municipal solid wastes was due to reduced evaporation since those plots treated had higher soil water content than control plots. These annual applications also eliminated the need to fertilize the crop. A rate of 100m $3ha^{-1}$ (40 tha^{-1}) was recommended to provide these benefits without any negative effects of increasing soil salinity or heavy metal content. Annual applications of composted municipal solid wastes were shown by Leno and Sudharmaidevi (2021) to replace the need for P fertilization. They also reported a continuous increase in soil organic matter each year in the top 5 cm of soil after surface applications of compost. Composted materials were an excellent source of P for plant growth and N and P did not limit ryegrass growth at rates of addition of biosolids compost greater than 2 % (w/w). There was a positive effect of increasing rates of biosolids compost and cow manure compost application on cumulative dry matter yields of ryegrass. Cow manure compost was shown to limit ryegrass growth by lack of available N, but could potentially provide N as a slow-release fertilizer.

While plant N uptake was highest in compost treatments, plants grown in soil treated with mature sewage sludge compost did not give a statistically higher yield than soil treated with inorganic fertilizer. Mature sewage sludge compost could be used as N fertilizer due to the level of nitrate formed during the maturation stage of composting. The fertilizer value of composts prepared from other sources (green-waste compost) would be lower due to the nitrogen content of the starting materials. The agronomic value of NPK in compost is 16 – 18 % of mineral fertilizer. The effect of one-time high-rate applications of compost was studied by Sharma *et al.,* (2019) using a rate of 155tha^{-1} tilled-in compost. The plots received annual fertilizer-N applications and were compared to a fertilizer only (no compost control). An increase in soil mineralizable-N was shown in years 3 and 6 after compost application. All compost treatments increased grass yields from year 2 onwards (until at least year 7). Compost also increased N uptake in grass compared to the fertilizer-only control. Food waste and yard trimmings compost produced the highest yields and N uptakes. Poblete-Grant *et al.* (2019) showed that mineral fertilizer in combination with compost significantly increased the dry matter yield of ryegrass. The compost used was shown to increase plant-available K, Fe, Mn, Zn, and Cu in the soil although, due to low dry matter yields, trace metal uptake by plants after compost application alone was not significantly affected. They recommended compost application in combination with NPK fertilizer. Geng *et al.* (2019) also recommended that compost application is complemented with mineral-N additions but, due to increases in N mineralization with repeated compost applications, after some time a reduction in mineral-N applied could be made. Soils with regular compost additions would have an increased N-delivering capacity over time.

An increase in mineralization after 7 years of a 10-year agricultural trial of compost was shown by Morra *et al.* (2021) which led to higher spring nitrate concentrations. The value of using compost is therefore long-term for supplying slow-release N for crop growth. Yield responses due to compost application were low at the beginning of the trial but increased with time. Compost at an application rate of 23ha^{-1}y^{-1} was shown to increase yields by 10 % on average over 10 years compared to the control. As long as nitrate and calcium levels in compost are low, the water-soluble phosphate content of compost will be high and it could have a similar fertilizing effect to super-phosphate. Soil available P was maintained at 'high' levels throughout a trial of urban compost applications at a rate of 14tha^{-1}. Soil available K also slightly increased in compost applications. Levels of K in composted urban refuse and aerobic/anaerobic sludge were not high in terms of crop requirement and deficiencies might be seen in crops with high potassium requirements.

2.9.4 Diseases suppression

The liquid extracts of composts are seen as alternative options to the use of traditional chemical fungicides and pesticides in response to the growing need for agriculture and food protection for environmental sustainability (Yatoo *et al.*, 2021). Compost technology is a valuable tool already being used to increase yields by farmers interested in sustainable agriculture (Hrynevych *et al.,* 2022). Now, professional growers are discovering that compost-enriched soil can also help suppress diseases and ward off pests (Kumari *et al.,* 2022). These beneficial uses of compost can help growers save money, reduce their use of pesticides, and conserve natural resources. In the poultry industry, composting has also become a cost-effective method of mortality management. Compost has the ability to diseases causative organisms Bellini *et al.* (2023).

Disease control with compost has been attributed to four possible mechanisms: (1) successful competition for nutrients by beneficial micro-organisms; (2) antibiotic production by beneficial micro-organisms; (3) successful predation against pathogens by beneficial micro-organisms; and (4) activation of disease-resistant genes in plants by composts. Scientists have enhanced the natural ability of compost to suppress diseases by enriching it with specific disease-fighting micro-organisms or other amendments. This amended or “tailored” compost can then be applied to crops infected by known diseases. Research has shown that tailored compost significantly reduced or replaced the application of pesticides, fungicides, and nematicides which could adversely affect water resources, food safety, and worker safety (Muhammed *et al.,* 2021)

2.10 Differences between Organic and Inorganic Fertilizers

The idea that organic fertilizer is significantly different from inorganic fertilizers is not new; however, until recently the unique properties of compost were overlooked (Zhang *et al.,* 2023).

Table 2.2: Comparison between organic and inorganic chemical fertilizer

Variable	Organic	Inorganic fertilizer

Source and preparation	Produced or prepared from organic materials (wastes, by-products, etc.) under controlled natural conditions.	Artificially Produced from synthetic materials
Cost	Cheap	Costly
Nutrients	Have unequal distribution of essential nutrients: nitrogen, phosphorus, and potassium.	Have equal distribution of essential nutrients; nitrogen, phosphorus, and potassium
Rate of nutrient release	Slow release	Immediate release after application.
Organic matter	Adds organic matter to soil which improves soil structure, improves water holding capacity, and reduces erosion.	Absent in chemical fertilizers.

Source: (Zhang et al., 2023).

2.11 Characteristics of Faecal Sludge

Estimating the quantities of faecal sludge generated and determining their characteristics are important steps in designing faecal sludge (FS) treatment technologies (Ahmed *et al.,* 2019). The collected or collectible daily per capita faecal sludge quantities are dependent on the technology type, desludging practices, how the technology is used, groundwater levels and on infiltration, and soil absorption capacities (Angelakis *et al.,* 2022). All of these variables result in a significant difference in faecal sludge characteristics within cities, and within the same type of containment technology in different locations (Jain *et al.,* 2022). Faecal sludge is either generated from on-site sanitation systems and/or through open defecation. According to Maqbool *et al.* (2022), much of the faecal sludge produced, collected, and disposed of in urban centers remains as yet unaccounted for. The number of faeces excreted daily by individuals varies considerably depending on water consumption, climate, diet, and occupation (Beene *et al.,* 2022).

However, Morone *et al.,* (2019), report that the amount of faeces produced by a person depends on the composition of the food consumed. For example, foods low in fibre such as meat, result in smaller amounts (mass and volume) of faeces than foods high in fiber (Butowski *et al.,* 2019). The only way to obtain an accurate determination of the amount at a particular location is direct measurement. Approximately 30-45 kg (wet weight basis) of faecal sludge is produced per person every year in developed countries corresponding to 10-15 kg of dry matter (Ali *et al.,* 2020). In 1999, Del Porto & Steinfeld reported an average faecal sludge generation rate of 50 grams per person per day based on the compilation of several studies. A study in Accra reported that the volume of faecal sludge generated per capita per day is 1 liter, 2 liters, and 0.2 liters for septic tank sludge (septage), public toilet sludge, and pit latrine sludge respectively (Shukla *et al.,* 2022).

2.11.1 Nutrient Status of Faecal Sludge

The nutrient content of faeces originates from the food consumed. It is estimated that the food nutrient content is distributed to the faecal fraction in the proportions: of 10-20% nitrogen (N), 20-50% phosphorus (P), and 10-20% potassium (K) (Samal *et al*., 2022). About 20% of feacal nitrogen is ammonia, biochemically degraded from proteins, peptides, and amino acids, some 17% is found in living bacteria and the remainder is organic nitrogen combined in molecules such as uric acid and enzymes. The nutrients contained in faeces in Sweden are on average 550 g N, 183 g P, and 365 g K per person per year (Papangelou and Mathijs 2021; Krounbi *et al*., 2019). Urine contains the largest proportion of plant nutrients found in the household waste and wastewater fractions. The amount of plant nutrients excreted via urine per person per year has been measured at 2.5-4.3 kg N, 0.4-1.0 kg P, and 0.9-1.0 kg K (Abebe 2017; Bagchi, 2016). Nartey (2013), analyzed measurements on the nutrient content of urine, including previous studies, and found the annual excretion rate per person in Sweden to be about 4000 g N, 330-365 g P, and 1000 g K. Together, the nutrients in urine and feces in Sweden add up to some 4500-4600 g N, 500-550 g P and 1400 g K per person per year. Based on FAO data on food supply, Ddiba (2016) estimated the quantity of nutrients in Ugandan excreta to be 2500 g N and 400 g per person per year.

2.11.2 Pathogens in faecal sludge

The solid fraction or biosolids component of sludge contains microorganisms, including some that are potentially harmful, toxic metals, and macro- and micronutrients (Sharma *et al.,* 2017). The actual species and density of pathogens existing in sewage and for that matter faecal sludge depend on the health status of the local community and the sewage sludge treatment processes (Jain *et al.*, 2022). Similarly, Stockdale and Hill (2021), reported that the faeces of a healthy person contain large numbers of bacteria of many non-pathogenic species. The presence of some pathogenic microorganisms (Gastrointestinal pathogenic microorganisms) in faecal sludge is an indication of infection amongst the population contributing to the faecal sludge (Capone *et al.,* 2020). The reason is that Gastrointestinal pathogenic microorganisms do not occur as a natural part of normal intestinal microbiota.

Low-cost treatment options rely on natural means that use microorganisms to decompose feacal sludge. The most common microorganisms present in faecal sludge are bacteria, fungi, actinomycetes, and algae (Beroigui *et al.,* 2020). These microorganisms are often heterotrophic and thus rely on a carbon source derived from organic matter as food.

Furthermore, the survival or death of pathogens in the faecal sludge depends upon some factors, such as temperature, moisture content, and competition from indigenous microflora (Alegbeleye and Sant'Ana, 2020). Other factors, such as predation, pH, sunlight, oxygen, and texture also influence the pathogen die-off.

2.11.3 Heavy Metals and Toxic Organics in Faecal Sludge

The greatest concern in sludge utilization is on heavy metals because they may be present in relatively high concentrations in compost and accumulate in soil with continuous application (Sarathchandra *et al.,* 2022). Several studies have been carried out on the accumulation of heavy metals in plant–soil systems after the application of SS compost. The maximum contamination of heavy metals takes place in the top layer of soils (Barsova, 2019). However, through shrink-swell cracks, heavy metals can penetrate the subsoil layers and consequently contaminate the surface groundwater (Ikeagwuani and Nwonu 2019). With SS, Stevenson's study showed that an annual application of 20 tons ha-1 of SS for 20 years would increase 8 mg kg^{-1} of Co, 180 mg kg^{-1} of Cu, 270 mg kg-1 of Pb, and 890 mg kg of Zn (Rayne and Aula, 2020). To avoid heavy metal pollution in soil, in Japan, when SS is applied to agricultural land, it has to meet the standards defined by the Japanese fertilizer law. For example, the upper limits for As, Cd, and Hg in sludge are 50, 5, and 2 mg kg^{-1}. After applying to the soil, the heavy metal accumulation in farm soils will be controlled by the reference to Zn content with the upper permissible level of 120 mg kg^{-1} soil. (Xu *et al.,* 2022).

2.12 Rice Husk

Rice Husk (RH) is waste generated from the agriculture industry, and this waste is in abundance in Malaysia. Based on the statistics reported by the Food and Agricultural

Organization (FAO), about 2.6 million tons of paddy were harvested from Malaysia in 2016. However, about 20% of the harvested paddy was husk (Tiwari *et al.*, 2017). Fernandes *et al.* (2016) reported that the major components of RH are cellulose (50%), lignin (30%) and organic compounds (20%). RH undergoes a burning process to generate heat used in the boiler as industrial fuel for generating steam in a turbine to provide electricity (Prasara and Gheewala, 2017). The burning process of RH under controlled temperature will produce a waste product known as Rice Husk Ash (RHA). During the incineration process, about 18–20 wt% of RH is converted into RHA (Pode, 2016). Bakar *et al.* (2016) reported that RHA possesses more than 90% silica content and some metallic impurities which include potassium (K), iron (Fe), manganese (Mn), calcium (Ca), sodium (Na), and magnesium (Mg). Mostly, the burning of RH disposed at the landfill usually generates RHA.

This RHA can cause an environmental problem (air pollution) and space limitations. To prevent the environmental problems emanating from RHA, many efforts have been made to utilize RHA in the production of silica gel (Rungrodnimitchai *et al.*, 2015), fire bricks, the hydrophobic coating on glass, activated carbon, soil conditioner, and bio-fertilizer. In addition, RHA can serve as a potential source of organic fertilizer through composting process. This is due to the abundance of silica in RHA that can enhance plant growth. In many plant systems, silica accumulated in the solid form creates intracellular or extracellular silica bodies (phytoliths) that are crucial for growth, rigidity, mechanical strength, predator and fungal defense, stiffness, as well as cooling. Moreover, Badar and Qureshi (2014) found that composted rice husk improved the organic content of the soil effectively improving biochemical parameters and growth of sunflower plants.

2.13 Coliforms as Indicator Organisms in Compost

It is well established that compost contains a diverse group of organisms dominated by bacteria and fungi participating in the decomposition of organic matter (Biyada *et al.,* 2021). Bacteria can grow and multiply in both oxygen-rich (Aerobic) and low or no oxygen (Anaerobic) environments. Bacteria from genera such as *Enterobacteria*, *Serratia, Nitrobacter, Pseudomonads, Bacillus, Staphylococcus,* and various *Actinomycetes* as well as fungi such as *Trichoderma spp.* have been isolated from mature composts. Subsets of these species known as facultative anaerobes, thrive in low-oxygen environments but can grow under aerobic conditions.

It is proposed that the presence of facultative anaerobes in mature compost is likely associated with disease-suppressive traits. Studies have shown various fungal root rot diseases have been suppressed by incorporating compost into soil or soil-fewer growing media. Similarly, the microbial populations of nonaerated composting teas (NCT) and aerated composting teas (ACT) (Gea, 2021) have been described as being dominated by bacteria. It is stated that with ACT aerobic bacteria predominate (Yang *et al.,* 2019), while with NCT the population of bacteria is mainly facultative anaerobes (Beck, 2019). There is considerable interest among growers, producers, and the scientific community in manipulating the brewing processes to obtain the optimum composition of beneficial microbes that include both aerobic and facultative anaerobic groups. To date, populations of organisms have been variable with both NCT and ACT making any comparison of available scientific experimental results difficult (Ready and Price, 2021). In addition, the lack of a uniform standard method for reporting the compost tea microbiology adds to the complexity of the brewing process. Commercial suppliers advertise pre-packaged microbial inoculums that can be brewed on their own, added to the compost source, or to ACT following the brewing process. One of the popular microbial inoculums is Effective

Microorganisms (EM-1). This is a cocktail comprised of a large population of facultative bacteria, yeast, enzymes, trace minerals, vitamins, and organic acids. Many of the claims made for compost tea such as plant-promoting growth, and disease-suppressive traits are also made for EM-1. The groups of organisms present in the EM-1 include lactic acid bacteria, phototrophic or photosynthetic bacteria, and yeast, with a diversity of species within each organism group. The material safety data sheet provided by suppliers does not identify the exact species or supplements included in the cocktail.

There is considerable evidence in microbiology books on the benefits of lactic acid bacteria and yeast in fermentation and decomposition processes. Photosynthetic bacteria can assist in converting energy into food sources for plants. However, claims supporting the roles of these beneficial microbes in plant disease suppression remain elusive. Equally unknown is the effectiveness of the balance of species in compost tea amended with EM-1. Other microbial formulations include Fungi in the genus *Trichoderma* that have been known since at least the 1920s for their ability to act as biocontrol agents (a term coined for beneficial organisms with the ability to suppress pathogens) with successful results in maize (Jankar *et al.,* 2020). *Trichoderma* species grow naturally around the plant roots and feed or parasitize on pathogenic fungi. However, if pathogenic fungi are not present in the soil, the addition of *Trichoderma* can have little or no benefits as they will die off without feeding on pathogens (Poveda *et al.,* 2020). Increasing the microbial diversity without understanding the role of each species in the context of the plant‘s natural environment can be risky, but is a power concept that needs to be explored further under controlled scientific experiments in the field.

2.14 Helminth Eggs as Indicator Organism in Compost

Rahman *et al.* (2022) found out that representatives of helminth ova are the most resistant to high temperatures for a longer period. It can therefore be assumed, that if all helminth ova in the compost are dead or deactivated, all other pathogens have also been removed. Helminth ova, mainly *Ascaris* and *Trichuris*, have been found in composting facilities (Zdybel *et al.,* 2019). A study on the effect of various factors in co-composting on helminth eggs (Nikiema, 2020) was carried out by a group in Ghana. They concluded that faecal sludge which was highly contaminated with helminth eggs, mainly *Ascaris* and *Trichuris*, when co-composted resulted in a highly safe product where the helminth ova were inactivated. Their report showed that the temperature of the heaps ranged from 43.5°C to a maximum of 58°C. The consistent higher temperature in the present study and the initial lower count of helminth ova in the sludge indicate that any helminth ova would be expected to be inactivated or killed during the composting process, as was observed. Based on the findings and reported data, it can be safely inferred that the initial samples, whose viability was not done, would not have contained any viable helminth ova at the temperature of the compost (Muntalif *et al.,* 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

This study was conducted at Akenten Appiah Menka University of Skill Training and Entrepreneurial Development (AAMUSTED). Mampong is the municipal capital of the Mampong municipality formerly (Sekyere-West district). It is one of the 48 municipalities of the Ashanti region. It lies about 57 km from Kumasi, the regional capital. The municipality shares boundaries with the Brong-Ahafo region to the north, Ejura-Sekyere

Odumasi districts to the northwest, Afigya-Sekyere to the south, and Sekyere-East to the east. The Municipality has an area of 2,346 square kilometers

3.1.2 Climate

The combined effects of climatic and geological conditions on the catchment's topography have yielded sub dendritic drainage pattern characterized by a network of channels and 12 streams. The site experiences double maximum rainfall patterns with peak rainfall periods in May-June and September-October and dry periods between July-August and November-February. The climate is typically tropical, with total annual rainfall between 1270 mm and 1524 mm (MSA, 2006; Winneba, 2020), with an annual average of 1300mm. The mean monthly temperature is about 25-32 C. The potential evapotranspiration (PET) is estimated at 1450mm per annum. The average humidity during the wet season is typically high (86%) and falls to about 57% in the dry period (MSA, 2006).

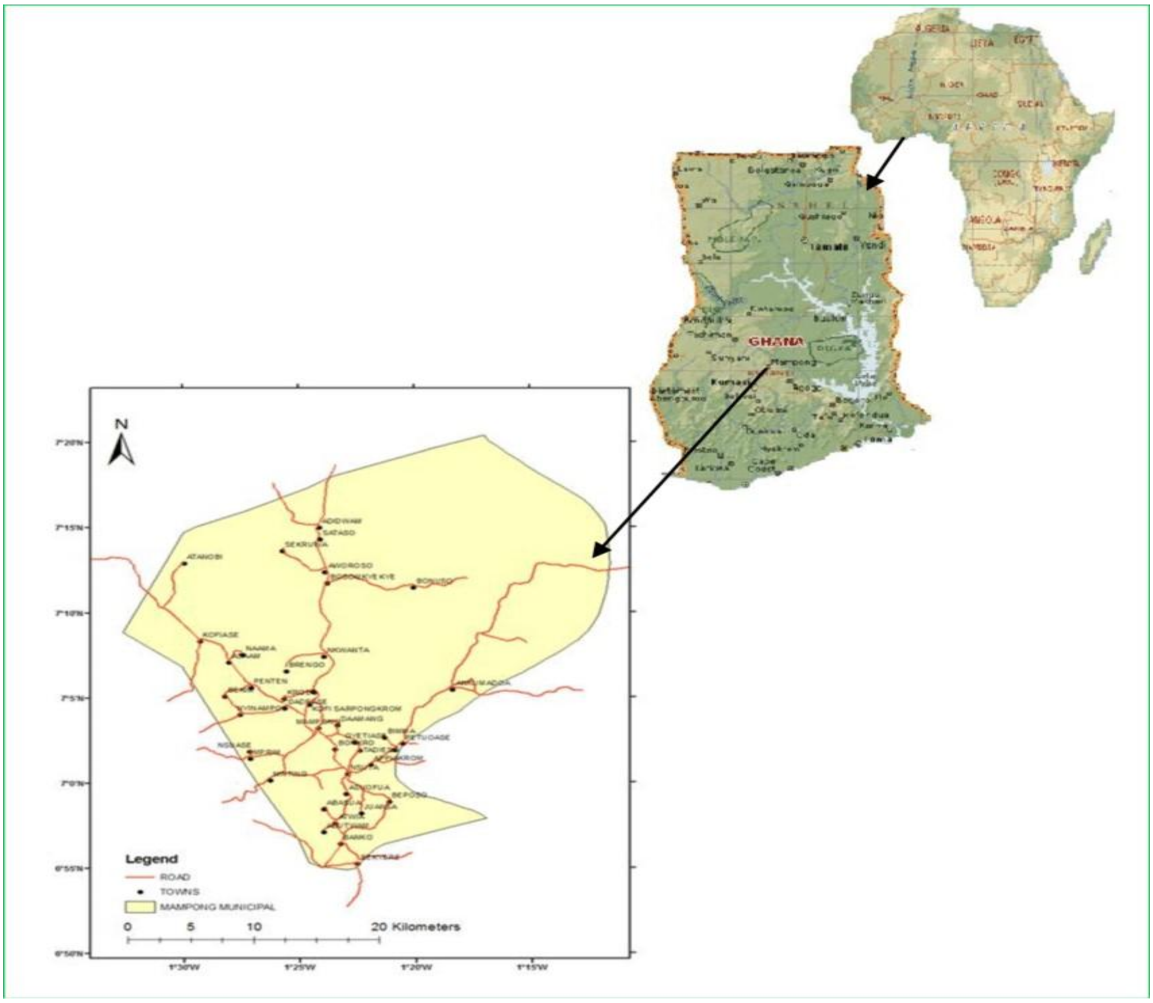


Figure 3.1: Map of Mampong Municipal. ***Source: Ghana Statistical Service (GSS)***

3.2 Data Collection

3.2.1 Collection of Rice Husk and Faecal Sludge

Rice husks for the compost were collected from two milling points in Mampong Township. Feacal matter was also collected from Mampong Municipal faecal sludge disposal site. A plastic container with a well-fitting cover was sanitized using alcohol and dried before it was used to collect faecal sludge from Mampong municipal disposal site to the composting site at Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development, Mampong campus.

3.2.2 Composting experiment design

Aerated (Turned) Windrow Composting method was used for the study in a pilot scale. The experiment utilized a heap composting pile which was economical to set up, and easy to manage composting activities in small-scale operation. Moreover, it was easy to monitor and collect data. The experiment had 4 treatments with 3 replications. Treatments were in ratios of rice husk to faecal sludge by volume to determine the best mixing ratios that produced quality compost. The composting experiments followed Complete Randomized Design (CRD). Thus, treatments were allocated to the experimental units or plots in a completely randomized manner (Hunter III *et al.*, 2020). It was assumed that on average, extraneous factors would affect treatment conditions equally, so any significant differences between conditions could fairly be attributed to the independent variables (Craig and Fisher, 2019).

Table 3. 1 Randomised experimental setup

1^{ST} SET	T_1 R_1	T_2 R_1	T_3 R_1
2^{ND} SET	T_4 R_1	T_3 R_2	T_2 R_2
3^{RD} SET	T_3 R_3	T_4 R_2	T_1 R_2
4^{TH} SET	T_4 R_3	T_1 R_3	T_2 R_3

Complete Randomized Designed (CRD) (Williams et al., 2002).

Arrangement of the treatment for the co-compost

1^{ST} SET (T1R1, T2R1, T3R1)

2^{ND} SET (T4R1, T3R2, T2R2)

3^{RD} SET (T3R3, T4R3, T1R2)

4^{TH} SET (T4R3, T1R3, T2R3)

(Where T1 is the control, T2 means treatment of the mixing composition 1:0.5, T3 of rice husk and feacal matter whereas R stands for the replicates).

3.3 Composting Procedure (Mixing ratio)

Four (4) different formulations of co-compost heaps were prepared from faecal sludge and rice husk. The ratios were 1:0, 1:0.5, 1:1, and 1:2 of rice husk to faecal sludge by volume, thus, 1:0 (90L) rice husk (control), 90L Rice husk to 45L faecal sludge, 90L Rice husk to 90L faecal sludge and 90L Rice husk to 180L faecal sludge respectively. The treatments were replicated for each in (‘R1, R2 and R3) for (T1, T2, T3 and T4) respectively (Table 3.2). The heaps were prepared by measuring in volume of both the rice husk and faecal sludge in their respective ratios. The composting heaps took an average size of 2 m long, 1.5 m wide, and 0.6 m high piles. The mixtures were thoroughly mixed up with a shovel to obtain a uniform mixture. Heaps were made in windrow. Manual turning was adopted every seven days, as it is the most common and least expensive method of composting organic wastes (Gbenatey *et al.*, 2017).

Table 3.2 The mixing ratio of rice husk and faecal sludge

Treatments	Pile A	Pile B	Pile C	Pile D
Mixing ratio (%)	1:0 90L Rice husk was used as a control.	1:0.5 90L Rice husk to 45L faecal sludge	1:1 90L Rice husk to 90L faecal sludge	1:2 90L Rice husk to 180L faecal
Turning rate	Every seven (7) days	Every seven (7) days	Every seven (7) days	Every seven (7) days (Manu, *et al.*, 2019)

3.4 Moisturizing and Turning

The compost was turned weekly that is every seven (7) days to increase the oxygen level to improve microbial activities (Manu, *et al.*, 2019). Water was added to each heap before they were turned. The addition of water to the compost affected the microbial activities as well. The compost pile was watered to about 40-60 per cent of compost volume before turning, following the turning sequence (Thomas et al., 2020). About 30 litres of water was sprinkled on each setup to moisten the compost before turning based on the set day and time for turning to maintain its optimum moisture content for the first month. The volume of water to moisten the pile kept reducing after the first month to the permissible level of the pile size which was between 20-25 liters.

3.5 Temperature measurement

During the composting period temperature was measured daily with a composting thermometer, at three different positions (bottom, middle, and top), the average was determined and recorded daily until the compost became more stable (Hemidat *et al.,* 2018).

3.6 Maturity Determination

To determine the maturity stages samples of compost were taken from each of the different compost treatments. Samples were picked at the start of the composting process (time, t=0), the 30th day of composting (time, t=30), the 60th day of composting (time, t=60), and the 90th day of composting (t=90) The samples were picked from each pile (bottom, center, and surface) and mixed in a sterilized container to get the composite sample for each pile, the samples were kept within the temperature of 4 °C before taking to the laboratory for analysis (Harvey *et al., 2*019). Each composite sample consisted of three sub-samples (200g each) for lab analysis.

3.7 Laboratory analyses

The laboratory analysis was done at Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong campus science laboratory, and (Environmental Quality laboratory and Civil Engineering department) in Kwame Nkrumah University of Science and Technology (KNUST).

3.7.1 Physico-chemical, nutrients and microbial characteristics of faecal sludge, rice husk and rice husk with faecal sludge co-compost)

Proximate analysis was done on both samples before the co-compost began. For rice husk, the following parameters were analyzed. The organic carbon (OC), nitrogen, phosphorus & potassium (NPK) both total and available were analyzed. Electrical conductivity (EC), pH, C/N, and moisture content (MC). For faecal sludge (FS), the following parameters were looked at; EC, NPK (Total and available) pH, C/N, FC, TC, C/N. The nutritional properties and microbial load of rice husk and faecal sludge co-compost were determined. The methods used for the laboratory analysis are described in (Appendix A).

3.8 Determination of Mixing Ratio that Gives Highest NPK Content and Lowest Bacterial Load

Performance Criteria for identifying the co-compost mixing ratio that gave the highest NPK and lowest microbial load were based on total NPK content, % mineralized NPK, and microbial load (total coliform and faecal coliform) in the respective rice husk-feacal sludge mixing ratios based on the data analysis.

3.9 Data Analysis

The results of data on composting materials during the composting period were analyzed using the Gen Stat 12th edition statistical package. This included analysis of variance (ANOVA) and least significant difference (LSD.

CHAPTER FOUR

RESULTS

4.1 Characterization of Rice Husk and Faecal Sludge

The organic carbon (OC) content of rice husk was very high with relatively high potassium (K) while that of feacal-sludge had a high potassium (K), total nitrogen (TN), and phosphorus (P) as compared to the lower levels found for rice husk (Table 4.1). Rice husk contained a high C: N ratio while that of faecal sludge was low. The pH of both rice husk and faecal sludge was rated slightly acidic. The electrical conductivity (EC) of rice husk was low while high in feacal sludge. Microbial load (total and feacal coliform) for faecal sludge was very high while that of rice husk was low.

Table 4.1: Characterization of raw rice husk and faecal sludge

Property	Rice Husk value	Faecal Sludge	P
OC (%)	45.03±1.68	32.66±.16	< 0.01
N (%)	0.47±0.17	3.15±0.11	< 0.01
C: N	95 ±3.30	10.36 ±2.17	< 0.01
P (%)	0.05 ±0.19	0.79 ±0.15	< 0.01
K (%)	0.81±0.14	1.26 ±1.10	< 0.01
pH	5.5 ±0.62^{a}	6.90 ±0.18	< 0.01
EC (ds/m)	0.77±0.15	5.92 ±0.17	< 0.01
Tot. Coliform (CFUg^{-l})	2.3x10^{3}	2.4x10^{17}	< 0.01
Feacal Coliform (CFUg^{-l})	0	4.2x10^{13}	< 0.01
Moisture (%)	21.1±1.16	90.24±0.10	< 0.01

(Source: field experiment)

4.2 Physiochemical Properties and Microbial Load as Affected by Compost Mixing Ratios

4.2.1 Temperature

The daily temperature recorded showed the same pattern for all the treatments (RF1:0-RF 1:2). It started from 30.0 °C reached maximum temperature within the first week at 55.0 °C and dropped back to 25.0 °C toward the end of the composting process. Among the RF mixing ratios, RF (1:2) produced the highest temperatures followed by RF (1:1) and RF (1:0.5). The temperature within the first 40 days showed that all RF mixing ratio treatments recorded higher temperatures than Rice-husk only. A temperature measured for all the treatments after 40 days showed low temperature at 25.0 °C and was constant to the end of the treatment (Fig 4.1).

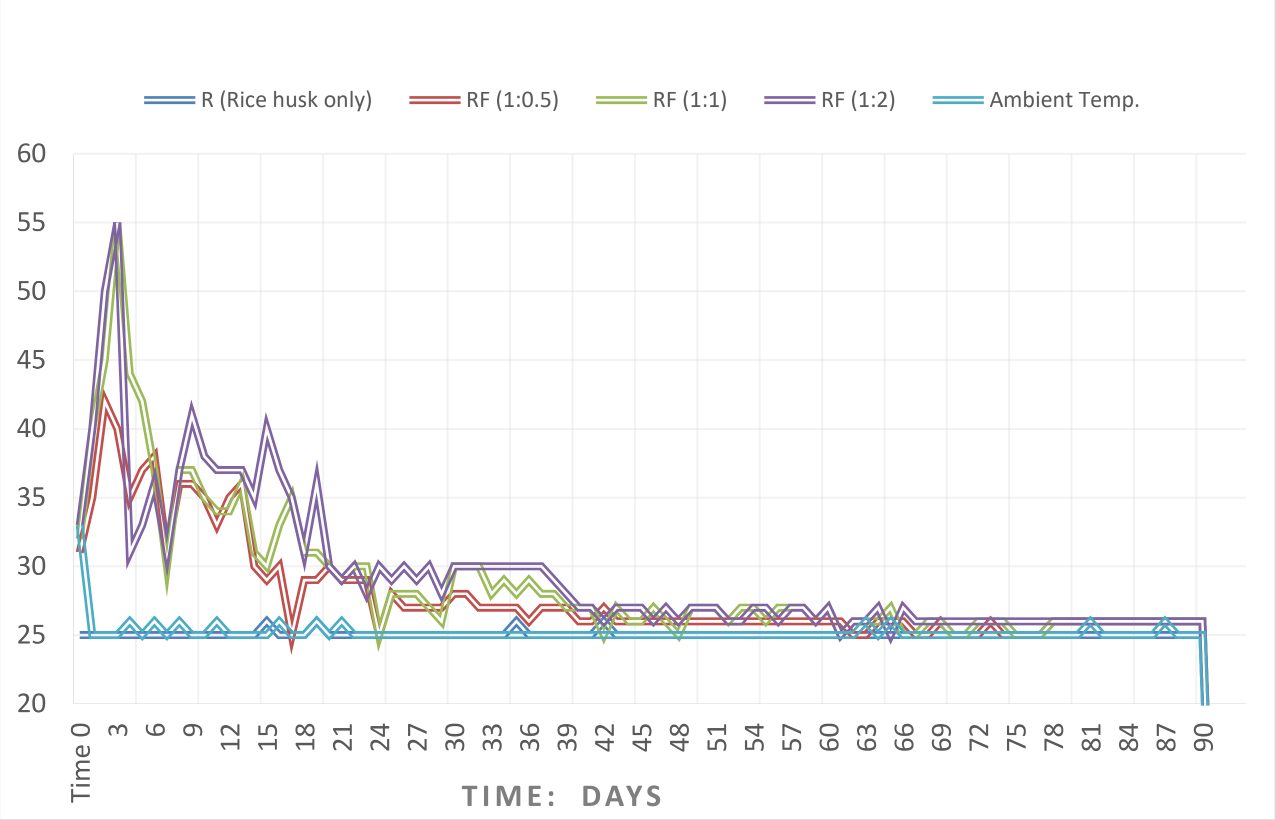


Fig 4.1: Temperature of mixing ratios for rice husk and faecal matter co-compost

4.2.2 pH and Electrical Conductivity

Rice husk and feacal sludge (RF) ratios recorded different pHs throughout the experiment except on day 30 when RF (1:0.5) was comparably the same to sole rice husk of pH 6.2 (Table 4.2). Also, on the 60th day R (1:0) and RF (1:1) had the same pH of 6.8 (Table 4.2). Electrical conductivity values for all rice husk-feacal sludge treatments were higher (p <

0.05) than for sole rice husk (Table 4.3). The EC of RF ratios were significantly different ($p < 0.05$) with a corresponding increase in feacal sludge contents.

Table 4.2: Levels of pH in RF co-composting treatments

Treatments	Day (0)	days (30)	Day (60)	Day(90)
R (Rice husk only)	5.5 ^{a}	6.2 ^{a}	6.8 ^{a}	6.6 ^{a}
RF (1:0.5)	6.1 ^{b}	6.2 ^{a}	6.7 ^{a}	6.9 ^{b}
RF (1:1)	6. 2 ^{c}	6.4 ^{b}	6.8 ^{a}	6.8 ^{b}
RF (1:2)	6.4 ^{d}	6.6 ^{b}	6.6 ^{a}	6.9 ^{b}

Different alphabets indicate significant differences among treatments
(Source: field experiment)

Table 4.3: Levels of Electrical conductivity (ds/m) in RF co-composting treatments

Treatments	Day (0)	Days (30)	Day (60)	Day (90)
R (Rice husk only)	0.77 ^{a}	1.82 ^{a}	0.47 ^{a}	0.53 ^{a}
RF (1:0.5)	2.23 ^{b}	2.64 ^{b}	0.65 ^{b}	2.95 ^{b}
RF (1:1)	4.45 ^{c}	2.68 ^{c}	1.03 ^{c}	3.44 ^{c}
RF (1:2)	4.93 ^{d}	4.12 ^{d}	1.52 ^{d}	3.87 ^{d}

Different alphabets indicate significant differences among treatments
(Source: field experiment)

4.2.3a Total NPK and mineralized NPK at the end of the co-composting experiment

Among all the treatments, RF (1:2) had higher total N and P (mg/kg) of (2.1% and 0.98%) respectively followed by RF (1:1) and RF (1:0.5) which had (1.40%) for N and P% RF 1:1 (0.68), RF 1:0.5 (0.42) while rice husk only recorded the lowest at the end of the study with N% of (0.5) and P% of (0.4) (Table 4.4.). On the contrary, higher total K (mg/kg) was observed in sole rice husk followed by RF (1:0.5) and RF (1:1) while RF (1:2) recorded the least. Mineralized N and P were highest in RF (1:1) followed by RF (1:2) and RF (1:0.5) with the lowest recorded in sole rice husk. But mineralized K was more pronounced in RF (1:2) followed by RF (1:1) and RF (1:0.5) with sole rice husk recording the lowest (Table 4.4).

Table 4.4a: Levels of total NPK, mineralized NPK, and organic NPK on (RF) co-composting at (t=90 days)

Treatment	Total (mg/kg)	**(%)**	Mineralized (mg/kg)	**(%)**	Organic (mg/kg)	**(%)**
N						
R (Rice husk only)	5000	0.50	100	2	4900	98
RF (1:0.5)	14000	1.40	1260	9	12740	91
RF (1:1)	14000	1.40	2480	18	13520	82
RF (1:2)	21000	2.10	2940	14	18060	86
P						
R (Rice husk only)	4000	0.40	12O	3	3880	97
RF (1:0.5)	4200	0.42	320	8	3880	92
RF (1:1)	6800	0.68	680	10	6120	90
RF (1:2)	9300	0.98	1581	17	7719	83
K						
R (Rice husk only)	12200	1.22	1220	10	10980	90
RF (1:0.5)	10000	1.00	1400	14	8600	86
RF (1:1)	9300	0.93	1581	17	7719	83
RF (1:2)	7400	0.74	2072	28	5328	72

(Source: field experiment)

4.2.3b Levels of OC% in rice husk and feacal sludge co-composting mixing ratios

The organic carbon (OC) percentage was determined during the composting processes and at the end of the treatment cycle. The percentage OC at t=0 was 45.03%, 42.1%, 40.5%, and 30.2% for T1, T2, T3, and T4. After day 30 of composting, a decrease was recorded in the %OC for the treatments T1-T4 by the following (40.03%, 37.21%, 32.56%, and 29.09%) respectively. From day 60 to day 90 of the composting processes, the %OC dwindled but was not significant (Table 4.4b).

Table 4.4b Levels of OC% in rice husk and feacal sludge co-composting mixing ratios

Organic Carbon (%OC)

Treatment	Time 0	30 days	60 days	90 days
R(Rice husk only)	45.03^a	40.03^a	39.65^a	38.61^a
RF(1:0.5)	40.21^b	37.21^b	35.05^b	32.17^b
RF(1:1)	36.32^c	32.56^c	29.63^c	27.65^c
RF(1:2)	33.64^d	29.09^d	27.05^d	25.24^d
P value	<0.01	<0.01	<0.01	<0.01

Different alphabets indicate significant differences among treatments

(Source: field experiment)

4.2.4 Carbon to Nitrogen Ratio (C: N)

The C:N ratio was also a stability factor. There was a significant ($p < 0.05$) difference in C: N amongst the various treatments throughout the composting period (Table 4.5). The C: N for R (rice husk only) was linearly constant (95-93) throughout the composting period while that of all RF mixing ratios decreased C/N of (36.62-10.6). Carbon: Nitrogen contents in R (rice husk only) were higher than all RF mixing ratios by 297-392 % (RF 1:0.5), 387-544 % (RF 1:1), and 495-778 % (RF 1:2). Carbon: Nitrogen (C: N) recorded in RF 1:0.5 treatments was 36.2-18.17 higher than (RF 1:1) 25.15-14.46 and (RF 1:1) obtained higher C: N than that of (RF 1:2) which recorded 20.23-10.61. The order of C: N was: RF1:2 < RF1:1< RF1:0.5 < R (rice husk only) (Table 4.5).

Table 4.5: C: N ratio as influenced by rice husk-feacal sludge co-composting ratios.

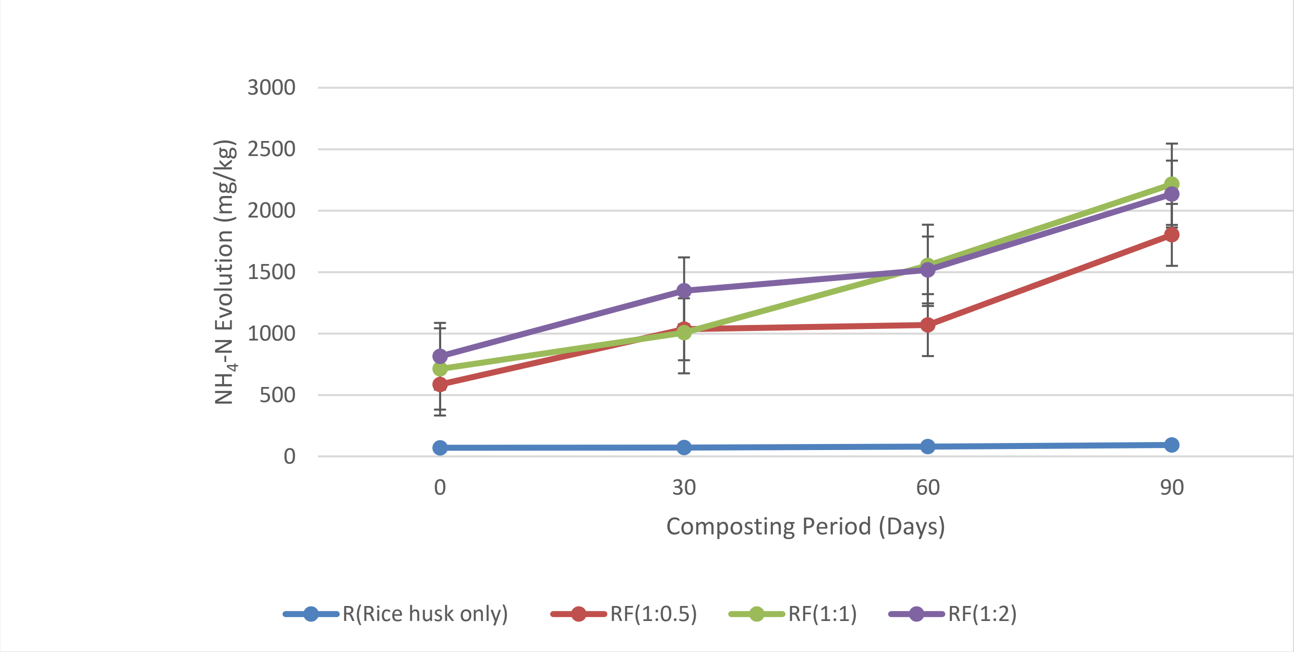
TREATMENTS	**C: N ratio as influenced by rice husk-feacal sludge co-composting ratios**			
TIME (DAYS)	**Day= 0**	**30 days**	**60 days**	**90 days**
R(Rice husk only)	95.12	95.08	94.4	93.17
RF(1:0.5)	36.62	27.82	23.74	18.91
RF(1:1)	25.15	19.5	16.1	14.46
RF(1:2)	20.23	15.97	12.21	10.61

Significance declared at 0.05* **(Source: field experiment)**

4.2.5 Ammonium-Nitrogen (NH_4^+-N*)*

The NH_4^+-N trends amongst the various compost mixing ratios were significantly different ($p < 0.05$). All the rice husk-feacal sludge (RF) mixing ratios, RF (1:0.5), RF (1:1), and RF(1:2) released from t=0 periods of composting with values of 585 mg/kg, 712 mg/kg and 814 mg/kg concerning the mixing ratio, t=90 significantly higher ($p< 0.05$) with values of 1803 mg/kg, 2215 mg/kg and 2135 mg/kg than sole rice husk (R) released from the start to the end of the composting periods with 70 mg/kg and 93 mg/kg respectively. The NH_4^+-N content was released from Sole Rice husk from the beginning of the composting periods with 70 mg/kg to the end of the composting periods with 93mg/kg.

The NH_4^+-N content in RF (1:1) from t=0 periods of composting through to the end of the composting t=90 increased with 712 mg/kg and 2215 mg/kg and this increment was higher than sole rice husk which recorded (70-93) from the beginning of the composting period to the end of the composting period by 13% - 40% respectively. Maximum Ammonium-Nitrogen released from RF (1:05) and RF (1:2) during the composting period was up to 1803 mg/kg and 2135 mg/kg by 40% and 42% respectively, which were higher than the maximum Ammonium-Nitrogen recorded in sole rice husk with 90mg/kg and by 29%. Ammonium-Nitrogen recorded from the beginning to the end of the composting period in RF (1:2) was higher than the Ammonium-Nitrogen recorded from the beginning to the end of the composting period in RF (1:0.5) by 14-42%, 13-40% respectively. Ammonium-Nitrogen recorded in RF (1:2) throughout the composting period was higher than Ammonium-Nitrogen levels in RF (1:1) by 14-42 % and 13-41% respectively. Ammonium-Nitrogen content was in order: RF (1:1) > RF (1:2) > RF (1:05) > R (Rice husk only) (fig. 4.2).



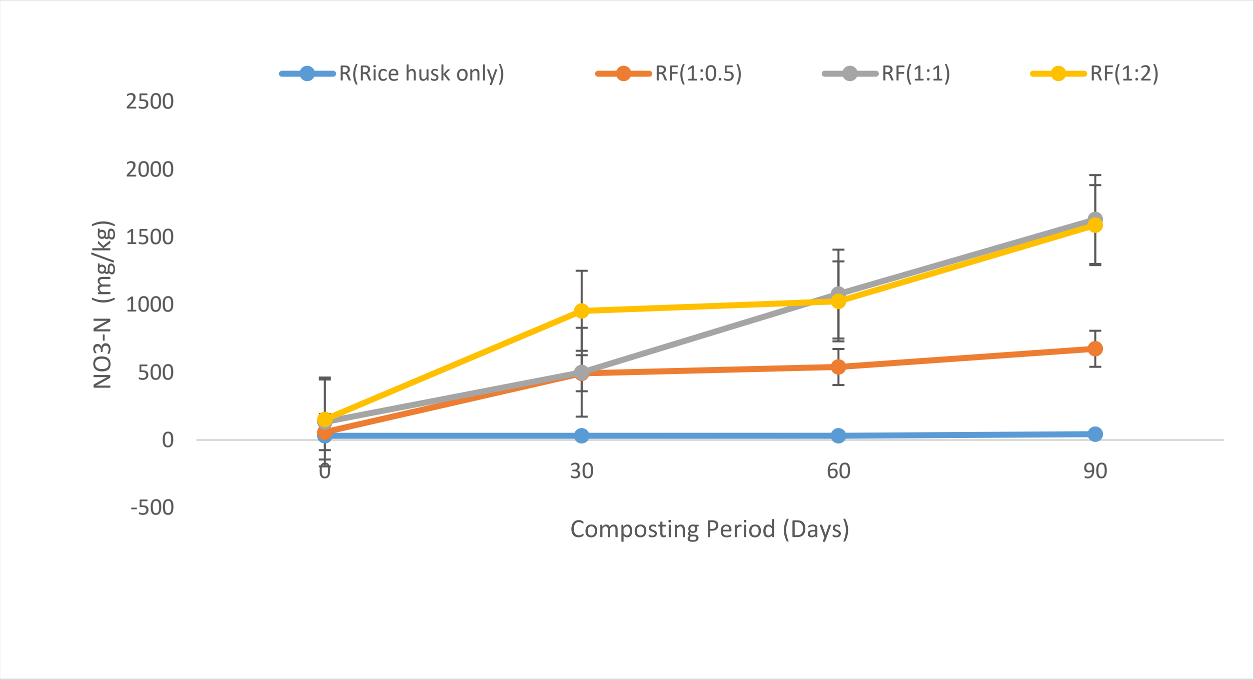
*Significance *declared at p level of 0.05*

Figure 4.2: Effects of rice husk-feacal sludge co-composting on Ammonium-Nitrogen

4.2.6 Nitrate-Nitrogen (NO_3 -N)

The study shows that there was a significant difference amongst the various compost mixing ratios at ($p < 0.05$) for Nitrate-Nitrogen (NO_3-N) throughout the study. Among these were RF (1:0.5), RF (1:1), and RF(1:2) the study showed t=0 periods composting with values of 59 mg/kg, 134 mg/kg, and 151 mg/kg for the mixing ratios. They were significantly higher at ($p < 0.05$) as compared to t=90 with values of 674 mg/kg, 1630 mg/kg, and 1588 mg/kg concerning the mixing ratios. Also, there was low Nitrate-Nitrogen (NO_3^--N) for the control thus sole rice husk (R) compost from the t=0 to t=90 of the composting periods with 32 mg/kg and 44mg/kg respectively as compared to the Nitrate-Nitrogen (NO_3^--N for the treatments with the faecal (fig.4.2.3). The Nitrate-Nitrogen concentrations of RF (1:1) from the early periods of composting through to the end of the composting increased linearly with 134 mg/kg and 1630 mg/kg respectively and this increment was higher than the sole rice husk from the beginning to the end of the composting period by 24 - 49% respectively.

Maximum Nitrate-Nitrogen recorded in RF (1:05) and RF (1:2) during the composting period were up to 674 mg/kg and 1588 mg/kg and by 38% and 43% respectively, which were higher than the maximum Nitrate-Nitrogen released from sole rice husk with 44mg/kg and by 31%. Nitrate-Nitrogen recorded from the beginning of the compost to the end of the composting period in RF (1:2) was higher than the Nitrate-Nitrogen recorded from the beginning to the end of the composting period in RF (1:0.5) by 25-42%, 23-38% respectively. Nitrate-Nitrogen recorded from RF (1:2) throughout the composting period was higher than Nitrate-Nitrogen recorded in RF (1:1) by 25-42 % and 24-41% respectively.



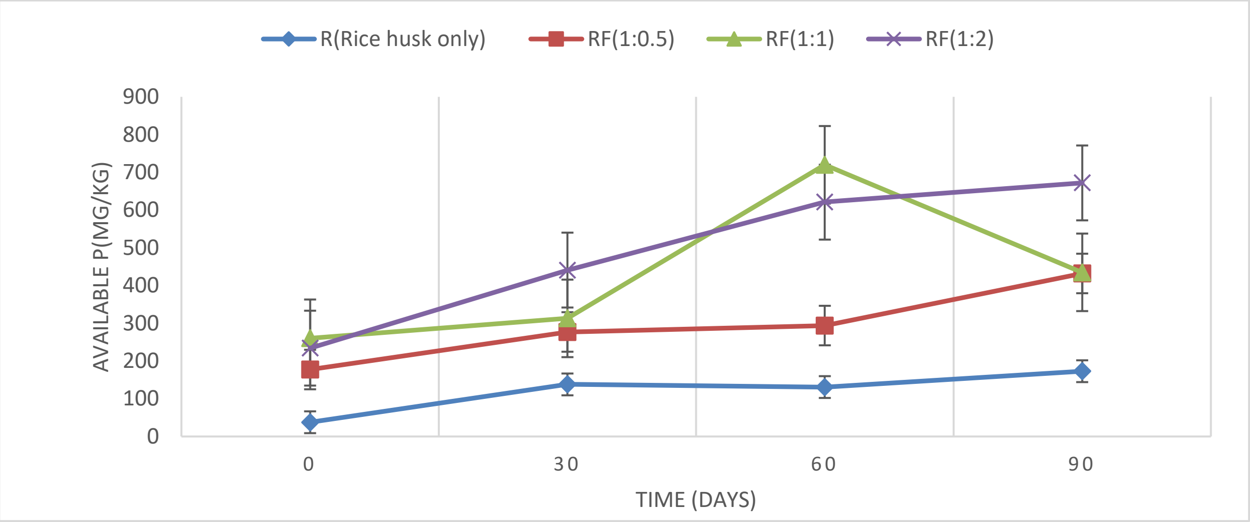
*Significance *declared at the p level of 0.05*

Figure 4.3: Nitrate-Nitrogen (NO_3-N) levels in rice husk-feacal sludge treatment co-composting ratios

4.2.7 Phosphorus

The available phosphorus content levels from the beginning to the end of the composting period were significantly ($p < 0.05$) different amongst the various treatments (Fig. 4.4). All the rice husk-feacal sludge (RF) mixing ratios, RF (1:0.5), and RF (1:2) recorded significantly ($p < 0.05$) higher increase for Phosphorus than sole rice husk (R) throughout the composting period except for RF (1:1) which increased from t=0 to t=60 and dropped slightly at t=90. This was higher than the Phosphorus content that was recorded from the early to the final stage of the composting process in sole Rice Husk (R). The Phosphorus content levels in R (Sole Rice Husk) increased slightly from the beginning to the end of the composting period 131mg/kg -173mg/kg.

The Phosphorus content recorded for RF (1:2) from the beginning to the end of the study was higher than all the other treatments. The Phosphorus content was in these order: RF (1:2) > RF (1:1) > RF (1:05) > R (Rice husk only).



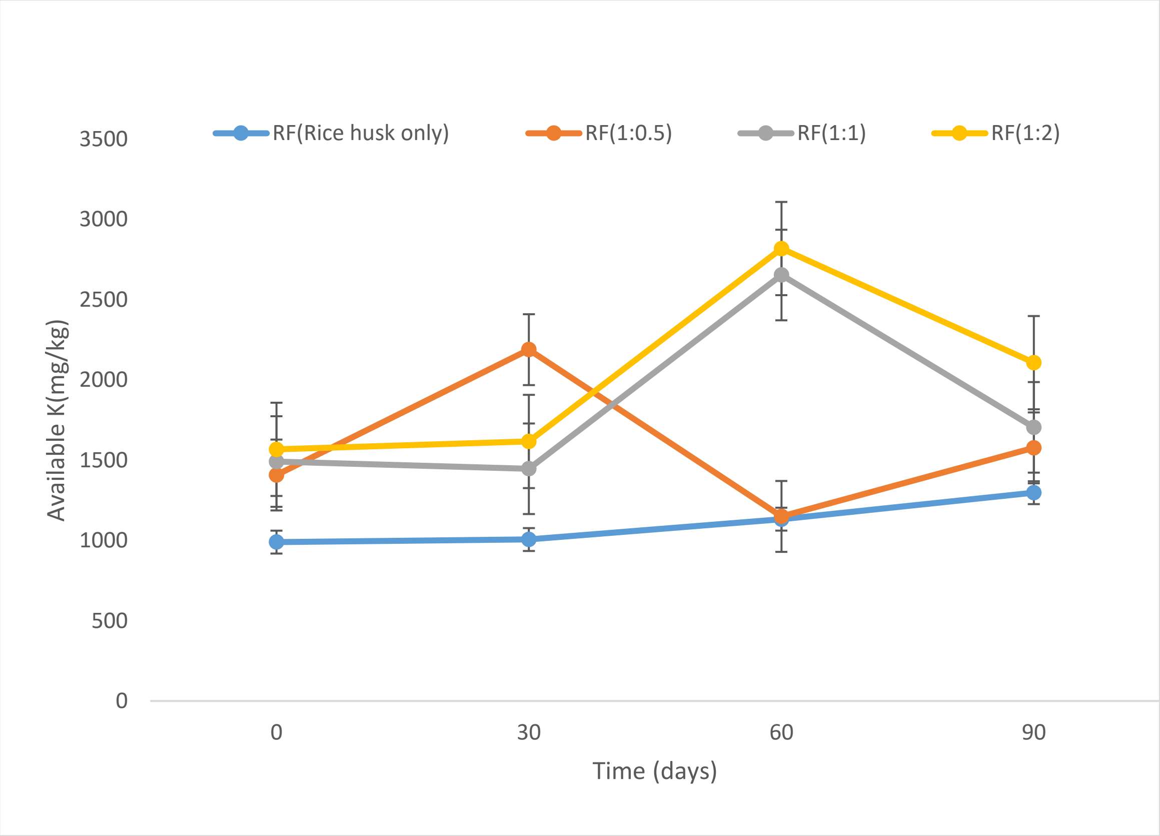
Significance declared at p level of 0.05.*

Figure 4.4: Levels of mineral P in rice husk –feacal sludge co-composting ratios

4.2.8 Potassium (K)

The available Potassium P found in the study was significantly different at ($p < 0.05$) amongst the various compost mixing ratios. All the rice husk-feacal sludge (RF) treatments, RF (1:0.5), RF (1:1), and RF (1:2) produced significantly higher Potassium as compared to sole rice husk (R) during the co-composting. The Potassium levels in the rice husk-feacal sludge (RF) treatments followed a sinusoidal trend meaning it rose and dropped again or dropped while that of R (Sole Rice Husk) was linear during the experiment. The Potassium levels from the RF (1:2) compost increased from the beginning to the 60th day and decreased towards the end of the treatments from 1617 mg/kg up to 2819 mg/kg and dropped to 2108 mg/kg, which was higher than the sole rice husk (R) (60-149 %), RF1:0.5 (33-144 %) and RF1:1 (6-23 %). Available Potassium recorded in RF

(1:1) was higher than sole rice husk (R) and RF1:0.5 with (31-134 %) and 8-131%, respectively. RF1:05 recorded higher available Potassium of 21-117% than sole rice husk (R) during the experiment. Available Potassium content was in the order: RF (1:2) > RF (1:1) > RF (1:05) > R (Rice husk only) (fig.4.5).



Significance declared at p level of 0.05.*

Figure 4.5: Levels of mineralized K in RF co-composting ratios

4.2.9 Microbial Load

Total coliform and feacal coliform markedly varied among the various mixing ratios at the beginning (time 0) and at the end (90 days) of the study. They were high with increasing feacal sludge content (Figure 4.6). The microbial load for rice husk-feacal sludge treatments (RF) at time zero was higher than that recorded during the cycle. However, microbial load recorded for rice husk only (R) rather increased during the composting experiment. Thus, microbial content in sole rice husk treatments was higher during the co-composting period than at time zero of the study

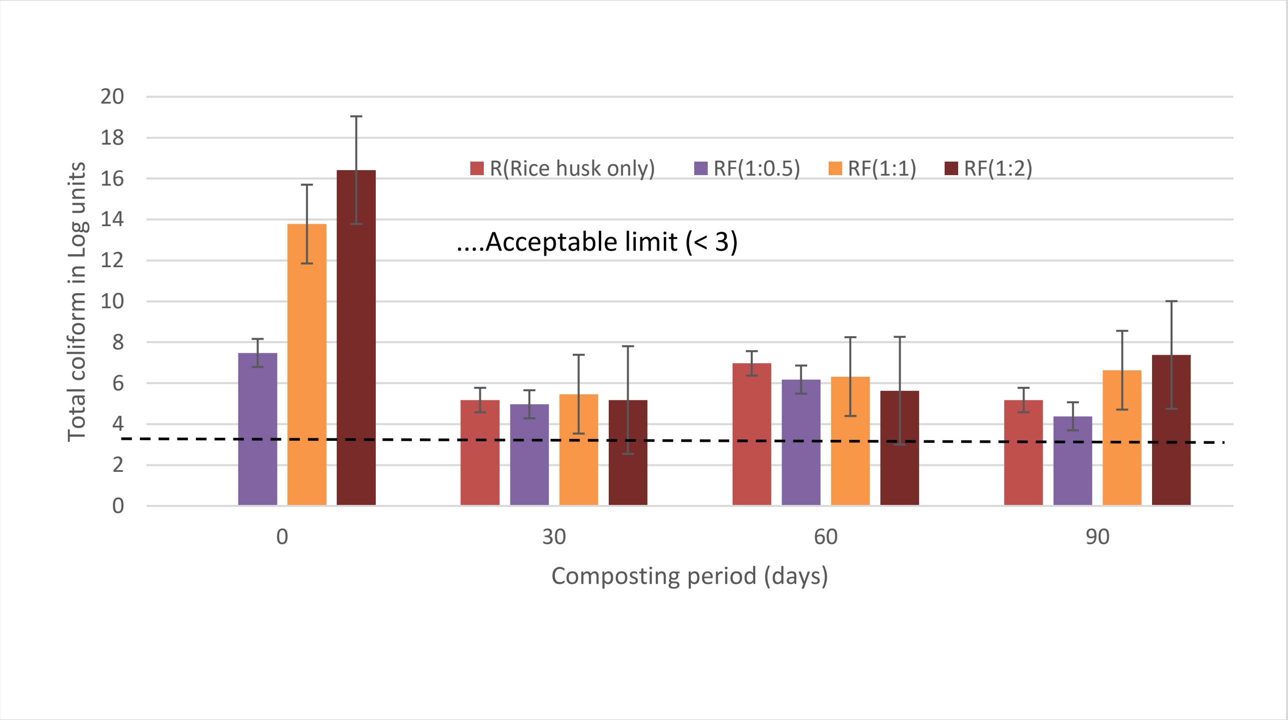


Figure 4.6a: Microbial load defined in log units: A) Total coliform

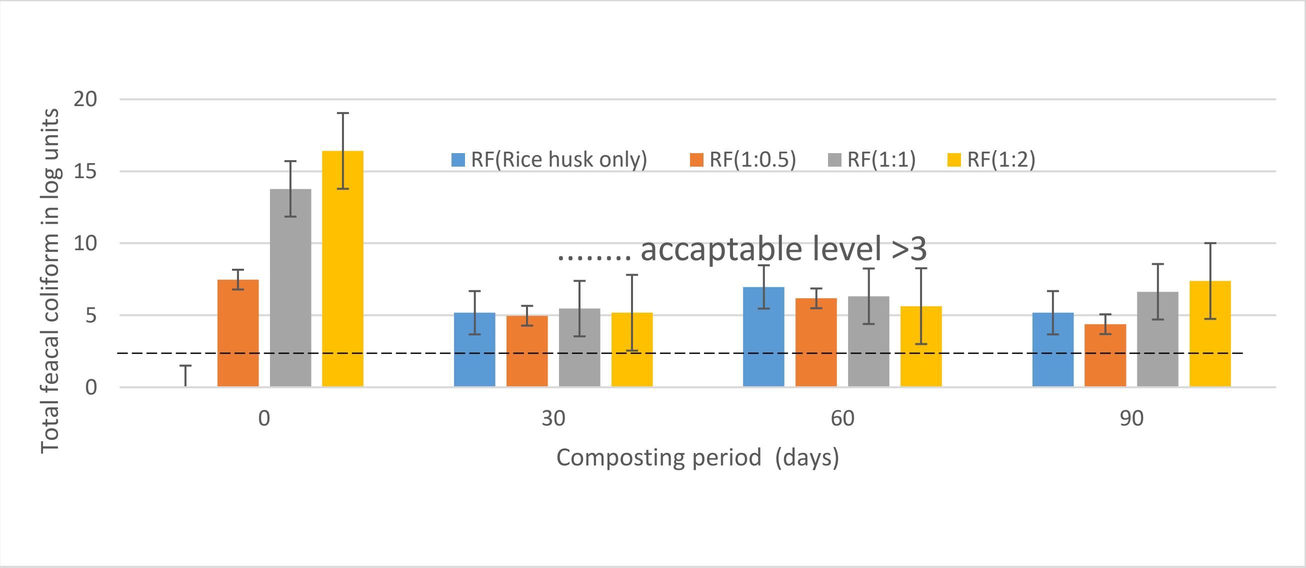


Figure 4.6b: Microbial load defined in log units: B) Faecal coliform

4.2.10 Maturity determination of RF co-compost.

Several studies on rice husk composting suggested a period of 90-150 days (approximately 3-5 months) using the windrowing method has been shown to result in a mature co-compost product. The ratio of NH_4^+-N to NO_3^--N was also used to determine the stability of the compost produced. Stable compost is said to have an NH_4^+-N/NO_3^--N ratio between 0.16-0.5 which gives a sense of the compost maturity depending on the feedstock. Ammonium to nitrate ratio for rice husk and feacal sludge co-composting found in studies elsewhere after 90 days was between 1.5-3. Which is not different from the findings in this study as follow, RF (Rice husk only) 2.13, RF (1:0.5)-2.67, RF (1:1) 1.36, RF (1:2)-1.34 (figure 4.3). The study showed that the ratio of NH_4^+-N/NO_3^--N at the end of the composting (day 90), all the treatments were above the 0.16-0.5 recommended ratio for stable composts, but were within the findings of other studies that used similar feedstock so it could be considered mature by the day 90.

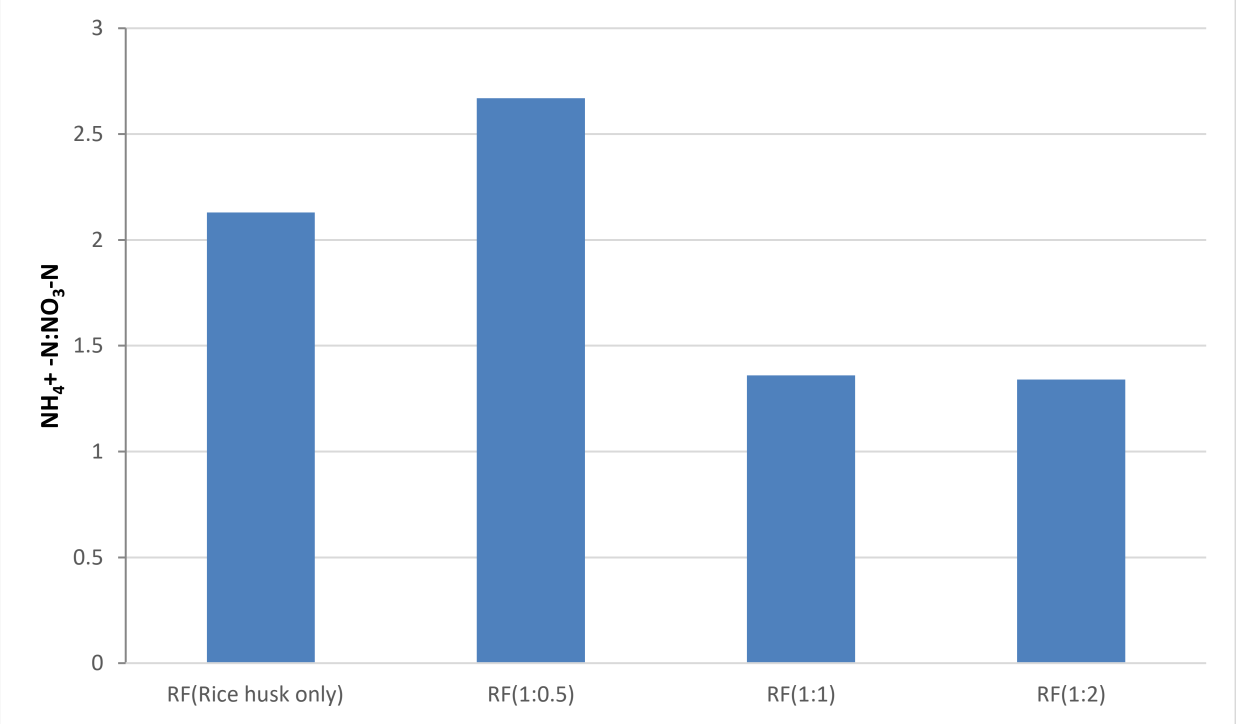


Figure 4.7 Maturity Determination of RF co-compost

4.3 Best Mixing Ratios Determination for Highest NPK Contents

To estimate the best mixing ratio that produced the highest quality compost, the analyses of variance on the total/mineralized NPK levels were observed in (Table 4.6). There was a significant difference between mixing ratios in terms of NPK content. Based on (Table 4.3), the mixing ratio that gave the highest NPK was RF (1:2) with total/mineralized NPK (2940 mg/kg, 1581 mg/kg, and 2072 mg/kg) respectively which was high above the other treatment. On its quality, though the microbial load of RF (1:2) was high, the treatment started on a very high microbial load of 13.58 cfu/100g to less than half by the end of the treatment at 6.38 cfu/100g based on these and other nominal values RF (1:2) performed better than the other treatments and therefore was considered the best mixing ratio for the rice husk and feacal sludge co-compost.

Table 4.6: Total and mineralized NPK content of compost mixing ratios at the end of the experiment

Treatments	Total ($mgkg^{-1}$)	Mineralized ($mgkg^{-1}$)
N		
RF(Rice husk only)	5000 ^{a}	100 ^{a}
RF (1:0.5)	14000 ^{b}	1260 ^{b}
RF (1:1)	14000 ^{b}	2480 ^{c}
RF (1:2)	21000 ^{c}	2940 ^{d}
P value	*< 0.001*	*< 0.001*
P		
RF(Rice husk only)	4000 ^{a}	12 ^{a}
RF (1:0.5)	4200 ^{b}	120 ^{b}
RF (1:1)	6800 ^{c}	680 ^{c}
RF (1:2)	9300 ^{d}	1581^d
P value	*< 0.001*	*< 0.001*
K		
RF(Rice husk only)	12200 ^{a}	1220 ^{a}
RF (1:0.5)	10000 ^{b}	1400 ^{b}
RF (1:1)	9300 ^{c}	1581 ^{c}
RF (1:2)	7400 ^{c}	2072 ^{d}
P value	*< 0.001*	*< 0.001*

The mean difference is significant at 0.05. Different alphabets denote differences in treatments

CHAPTER FIVE

DISCUSSION

5.1 Feedstock characterization

The quality of compost depends on the feedstock. In this study rice husk and faceal sludge were used. The proximate analysis of these materials showed a low and high N content in the rice husk and feacal sludge, respectively, and high OC (%) in the rice husk and a low OC (%) in faceal sludge. This is similar to the findings of other studies done elsewhere (Rathi *et al.,* 2018; Qadwe *et al.,* 2022). High OC (%) in rice husk and the high nitrogenous base of feacal sludge make the best pair for a co-compost since it might be the reason for the quality of the compost produced. Also, the High P content in faecal sludge (Mamera *et al*., 2022) and, high K in rice husk (Bakar *et al.*, 2016) could be the reason for the increase of P and K in the rice husk and faecal sludge co-compost. Acidic and slightly acidic rice husk and faecal sludge fall within the acceptable level agronomically and compost is assumed to balance the pH to permissible levels.

Rice husk is a byproduct of rice milling and is composed of cellulose, hemicellulose, and lignin. These compounds are all relatively resistant to decomposition, which can lead to the accumulation of organic acids in the husk (Qadwe *et al.*, 2022). In the same way, feacal sludge is a mixture of human waste, toilet paper, and other organic materials. While feacal sludge also contains potassium, its overall composition is different from rice husk. Feacal sludge undergoes microbial decomposition processes faster, and the resulting breakdown of organic matter might lead to the production of high concentrations of certain elements, including nitrogen and potassium as compared to rice husk. The electrical conductivity of rice husk (0.77 ds/m) was within the acceptable level but that of feacal sludge (5.9 ds/m) exceeded by 1.9 ds/m but that was not different from what is found in the literature *(*Singh *et al.*, 2022*)*. Higher total coliform and faecal coliform (Table 4.1) could result in a level that might be above the standard threshold after co-composting since not all the microbes may be killed or destroyed during the co-composting period. The electrical conductivity and microbial content mentioned in the statement suggest that feacal sludge may have a higher level of organic matter and microbial activity compared to rice husks. This can contribute to higher electrical conductivity and potentially higher levels of total coliform and feacal coliform.

5.2 Physicochemical Properties and Microbial Load of Rice Husk and Feacal Sludge (RF) Co-Compost Mixing Ratios

5.2.1 Temperature

Higher temperature for all RF treatments than rice-husk only till day 40 might be due to higher oxidation of organic matter in the RF ratios relative to rice-husk only. Thus, the presence of faecal sludge in the RF treatments provided a more suitable substrate for microbes to decompose the organic matter, unlike sole rice husk. Even though RF co-compost treatments for the first few days recorded temperatures up to 55 °C it did not exceed 55 °C. To ensure the safety of composts, the temperature during the composting must exceed 55 °C, within the first 2 weeks to kill a majority of the micro-organisms and above 60 °C to destroy the presence of seeds within the compost (Hashim, 2022). The temperature recorded in this study was in line with Manga *et al.* (2022) who recorded a maximum temperature of 45 °C at the initial days of the faecal sludge –agricultural wastes co-composting study. While the temperatures obtained in the current study did not meet safety requirements, they exceeded 45 °C reported by (Gocmen *et al.*, 2022).

Lower temperatures measured in this study might be attributed to the composting methods employed (open windrows) or to the dissipation of heat due to the small volume of the piles (Oshins *et al.,* 2022) and frequent turning. This was supported by the findings of a previous study by Yu *et al.* (2022) which indicated that heap sizes affect the temperature build-up during composting. Smaller heaps heat up faster than larger heaps. This is because the smaller surface area-to-volume ratio of a smaller heap means that heat is lost faster. Larger heaps can reach higher temperatures than smaller heaps. This is because the larger volume of a larger heap means that there is more material for the microbes to decompose, which generates more heat.

5.2.2 Total and mineralized NPK

There was significantly higher mineralized NPK in all RF ratios than in sole rice husk. This might be due to the impact of the micro and macro-organisms on the NPK content of the raw faecal sludge in the rice husk in this study (Samal *et al.*, 2022). Total N, P, and K content at the end of the study was high with increasing faecal sludge while total K was decreasing with increasing feacal sludge and Rice husk contents, respectively. This could be linked to high N, P (3 & 0.8 %), and K (1.26 %) in faecal sludge and rice husk in the study. It was estimated by other studies that the plant's nutritional content found in the faecal proportion were in a percentage proportion of 1-2% nitrogen (N), 2-5% phosphorus (P), and 1-2% potassium (K) (Bai *et al*., 2023; Kumar and Gupta, 2022). However, the current study unraveled that the plant nutrient content was distributed to faecal proportions: 3 % N, 0.8 % P, and 0.8 % K. This suggests that the mineralization of the faecal sludge releases richer amount of N, P, and K into the co-compost.The percentage of mineralized NPK (2-17, 3-10, and 10-28) at the end of the co-composting experiment was low for all treatments which makes organic NPK (83-98, 90-97, and 83-90 %) the major form of the total NPK in the co-compost product (Table 4.4). This implies that, to some extent, the compost may release NPK nutrients slowly to plants, unlike the mineral fertilizer, where all the NPK is in the plant-available form. Nevertheless, the co-compost could have a longer residual effect on the soil as the microbes continue to mineralize the organic NPK in the available form (Mensah *et al*., 2022).

The organic carbon witnessed a reduction throughout the composting processes but was not significant. Some factors such as temperature, and moisture content could account for the carbon decomposition. For instance, the temperature was too low throughout the treatment processes, which showed that microbes were not able to decompose the organic matter as quickly as possible. Similarly, rice husk’s cellulose, hemicellulose, and lignin are complex molecular structures that make them less accessible to microbial enzymes responsible for breaking down organic matter. The presence of these compounds in rice husk makes it more resistant to microbial degradation and decomposition processes. Additionally, lignin, in particular, is highly cross-linked to low water holding. Its complex structure could be the reason that makes it difficult for microorganisms to break it down and access the other components of rice husk (Rathi *et al.,* 2018). The higher lignin content in rice husk acts as a physical barrier, making it more difficult for microorganisms to access and break down the organic matter within the co-compost. This results in a slower decomposition rate for both the rice husk and the faecal sludge. Furthermore, the carbon-to-nitrogen ratio (C/N ratio) is an important factor in composting. Rice husk typically has a higher C/N ratio compared to faecal sludge, indicating a higher carbon content relative to nitrogen. This imbalance in the C/N ratio might lead to nitrogen limitation, as microorganisms require a sufficient amount of nitrogen to efficiently decompose organic matter. The lack of readily available nitrogen in the co-composting mixture can further slowdown the decomposition process.

Generally, the treatments with feacal sludge had significantly higher mineralized NPK % than sole rice husk piles. This indicates that the increase in feacal sludge component could lead to the compost result in higher NPK content of the final co-compost (Alarefee *et al*., 2022). The current study is supported by previous researchers (Greff *et al.,* 2022) who reported similar observations. However, RF (1:2) treatments which contain higher feacal sludge percentage recorded a higher % mineralized N PK than RF (1:1, 1:0.5, and 1:0).

5.2.3 Carbon to Nitrogen Ratio (C: N); Maturity Determination of RF co-compost.

A significantly decreased C: N in rice husk-feacal sludge mixing ratios compared to the rice husk only might be due to the presence of feacal sludge in the RF ratios which had high N content (Samal *et al.,* 2022). The microbes used the high N content in the RF to build their tissues which enhanced the degradation of the C-rich rice husk components in the various RF mixing ratios throughout the process (Zhang *et al.*, 2022). C: N ratio in RF treatments reduced in relation to increasing feacal sludge, compared to sole rice husk. This could be as a result of the high nitrogen base of the feacal sludge. Similar results were observed in a rice husk-chicken droppings/manure co-composting study where rice husk–chicken droppings ratio treatments recorded a significantly decreased C: N ratio relative to sole rice husk (Murimi and Gbedemah, 2019). However, C: N ratio for rice husk-chicken dropping ratios decreased with increasing chicken dropping which is in support of the current study. The high C: N ratio of rice husk makes it difficult to be degraded (Wang *et al.,* 2022), thus cannot be used for agricultural applications since it can hardly be decomposed in soil (Demir and Gülser, 2021). As such, applications of the sole rice husk would resulted in nutrient immobilization which depletes soil nitrogen other than supplying nutrients.

C:N had been used to determine compost stability. However, several studies on rice husk composting suggested a NH_4^+-N/NO_3^-—N ratio (Siriphan *et al.,* 2017; Rathi *et al.,* 2018; Nguyen *et al.,* 2019). A period of 90-150 days (approximately 3-5 months) using the windrowing method has been shown to result in a mature co-compost product. The ratio of NH_4^+-N to NO_3^--N was also used to determine the stability of the compost produced. A stable compost is said to have an NH_4^+-N/NO_3^--N ratio between 0.16-0.5 which gives a sense of the compost maturity depending on the feedstock (Bazrafshan *et al.,* 2016).

Ammonium to nitrate ratio for rice husk and feacal sludge co-composting found in studies elsewhere after 90 days was between 1.5-3.0 (Siriphan *et al.,* 2017; Rathi *et al.,* 2018; Nguyen *et al.,* 2019) which is not different from the findings in this study as follow, RF (Rice husk only) 2.13, RF (1:0.5)-2.67, RF (1:1) 1.36, RF (1:2)-1.34 (figure 4.3). The study showed that the ratio of NH_4^+-N/NO_3^--N at the end of the composting (day 90), all the treatments were above the 0.16-0.5 recommended ratio for stable composts, but were within the findings of other studies that used similar feedstock so it can be considered mature by the day 90.

5.2.4 Microbial Load as Influenced by Different Compost Mixing Ratios

Composting is one of the methods employed to sanitize feacal sludge pathogenically to achieve standards acceptable for agronomic applications. To meet this standard, total and feacal coliform concentrations must be < 1000 $CFUg^{-1}$ or < 3 log units $CFUg^{-1}$ (Lamolinara *et al.,* 2022). The reduction in total and feacal coliform load in the co-compost treatments at the end of the study compared to time zero can be attributed to the composting process. Composting involves the controlled decomposition of organic materials under specific conditions, including temperature, moisture, and oxygen levels. These conditions create an environment that is unfavorable for the survival and growth of coliform bacteria. However, the total and feacal coliform loads were still above a critical threshold level (Figure 4.7) for land applications. Microbial loads above the standard threshold in the various feacal sludge ratios at the end of the composting experiment might be due to the lower temperatures recorded which could not exceed 55°C needed for microbial destruction. This could also be because at time zero (0) the microbial contents were very high (8-18.5 log units $CFUg^{-1}$) for the various feacal sludge to rice husk treatments.

This could not reduce the microbial content to an acceptable standard (< 3 log units) during the co-composting study. In a related study by Nartey *et al*. (2017), all mixing ratios of feacal sludge co-composted with cocoa pod husk reduced total and feacal coliform (from 4.5-5.0 log units CFUg^{-1}) to an acceptable threshold (2.5-2.9 log units CFU g^{-1}) at the end of the composting study. This could be due to moderate pathogen loads (< 5 in log units CFU g^{-l}) in all the mixing faecal sludge ratios at time zero translating into a reduction to meet the threshold limit (< 3 log units) at the end of the experiment. Moderate pathogen load in the raw faecal material observed by Levira *et al*. (2023), could be linked to dewatering of the faecal sludge (removal of the liquid fraction) before co-composting, unlike the current study where fresh feacal sludge (solid plus liquid fraction) was used. The liquid fraction of faecal sludge might contain a higher microbial load. Hence, the observed high microbial load in the current study. Dewatering the feacal sludge before co-composting could help reduce the microbial density which will result in a level that meets the standard thresholds for land applications.

5.3 Determining best mixing co-compost ratios

Determining the best mixing co-compost ratios involves assessing the nutritional content and other nominal values in a different mixing ratio of co-compost, specifically RF (1:1), RF (1:2), RF (1:0.5), and (1:0) sole rice husk using analysis of variance to find out the significant differences. The study suggested that RF (1:1) and RF (1:2) had relatively similar NPK content, indicating that they contained comparable levels of nitrogen, phosphorus, and potassium (Table 4.4). Additionally, these two mixing ratios exhibited lower microbial loads compared to RF (1:0.5) and (1:0) sole rice husk, indicating a reduced presence of microorganisms (Figure 4.6). However, when comparing RF (1:1) and RF (1:2) with RF (1:0.5) and (1:0) sole Rice Husk, there were significant differences in both

NPK content and microbial load. This suggested that RF (1:0.5) and (1:0) sole rice husks had distinct characteristics in terms of nutrient composition and microbial levels.

Based on the analysis of variance and the nominal values of the compost quality, in terms of high NPK content and low microbial load for mixing ratios RF (1:1), RF (1:2), RF (1:0.5), and (1:0). The study concluded that RF (1:2) provided the best compost mixture based on its relatively higher NPK content and lower microbial load compared to the other mixing ratios since none was below the recommended threshold.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Composting rice and faecal sludge rather than disposing them into the environment is an environmentally sound means of recycling rice husk which is farm residues and faecal sludge into valuable soil amendments with many uses. At the end of the study this are the key findings;

- Raw feed stocks characterization showed that raw rice husk is low in that nutrients and microbial load while feacal sludge is high in nutrients and microbial load. However, the faecal sludge had a high level of NPK which impacted the RF co-compost positively.

- The mixing ratio of co-compost, specifically RF (1:1), RF (1:2), RF (1:0.5), and (1:0) sole rice husk using analysis of variance to find out the significant differences
- The physicochemical analysis of RF co-compost revealed that RF (1:1) and RF (1:2) ratios recorded high nutrient contents compared to RF (1:0.5) and control RF (1.:0).
- In terms of microbial load, RF (1:2) recorded high total and feacal coliform density followed by RF (1:1) and RF (1:0.5).
- The study showed that the ratio of NH_4+-/NO_3- at the end of the composting (day 90) was above the 0.16-0.5 recommended ratio for stable composts, but it was within the findings of other studies that used rice husk and faecal sludge as feedstock so it can be considered mature by the day 90.
- The end of the composting process showed RF (1:2) mixing ratio as the best compost among the co-composting treatments based on total NPK, mineralized NPK content, C: N ratio, and microbial load at the end of the co-compost experiment.

6.2 Recommendations

The following are the recommendations made:

- It is recommended that Rice husk be co-composted with feacal sludge in a ratio of 1:2. Farmers should be educated to mix rice husk to faecal sludge in the ratio of 1 part of rice husk to 2 parts of faecal sludge and should be composted for 90 days after which the compost would be ready for use in farming practices with maximum results.
- Policymakers should enforce that rice husk and feacal sludge should not be disposed of into the environment but rather be recycled into fertilizer products such as compost for both agronomic and environmental benefits.

- The government of Ghana and non-governmental organizations should organize farmers around rice farming communities and educate them on the usefulness of their farm waste especially rice husk as raw material for compost fertilizer production.
- Further study should be conducted on the compost from best mixing ratio to tested on crops against the chemical fertilizers to ascertain its agronomic efficiency.

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APPENDICES

APPENDIX A:

Physicochemical Parameters

pH

pH would be measured in a 1:1 rice husk-water and faecal matter-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Approximately 25 g of rice husk and faecal matter would be weighed into a 50 ml polythene beaker and 25 ml of distilled water would be added the samples. The sample-water solution would be stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH would be read by immersing the electrode into the upper part of the sample solution and the pH value would be recorded.

Total Carbon (C)

Total carbon would be determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). The procedure involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate would be titrated against ferrous sulphate. Approximately 1.0 g of air-dried sample of rice husk or faecal matter would be weighed into a clean and dry 250 ml Erlenmeyer flask. A reference sample and a blank would be included. Ten ml of 0.1667 M potassium dichromate (K2Cr2O7) solution was accurately dispensed into the flask using the custom laboratory dispenser. The flask would be swirled gently so that the sample would be made wet. Then using an automatic pipette, 20 ml of concentrated sulphuric acid (H2SO4) would be dispensed rapidly into the soil suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for about 30 minutes, after which 100 ml of distilled water would be added and mixed well. Ten ml of ortho-phosphoric acid and

1 ml of diphenylamine indicator would be added and titrated by adding 1.0 M ferrous sulphate from a burette until the solution turns dark green at end-point from an initial purple colour. About 0.5 ml 0.1667 M K2Cr2O7 would be added to restore excess K2Cr2O7 and the titration would be completed by adding FeSO4 drop-wise to attain a stable end-point. The volume of FeSO4 solution to be used would be recorded and % C calculated. Calculation:

The organic carbon content of soil was calculated as: % O. C= ....eqn (1)

Where; M = molarity of Ferrous sulphate solution

V1= ml of ferrous sulphate solution required for blank

V2= ml of ferrous sulphate solution required for sample

S = weight of air – dry sample in grams 41

Mcf= moisture correction factor 0.39= 3 x 0.001 x 100% x 1.3 (3= eqivalent weight of carbon) 1.3= a compensation factor for incomplete combustion of organic carbon.

Total nitrogen (N)

Total nitrogen would be determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of rice husk or faecal matter would be weighed into a Kjeldahl digestion flask and 5 ml distilled water would be added. After 30 minutes, a tablet of selenium and 5 ml of concentrated H_2SO4 would be added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask would be removed after a clear mixture would be obtained and then allow to cool. About 40 ml of distilled water would be added to the digested material and transferred into 100ml distillation tube. Twenty ml of 40 % NaOH would also be added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material would be distilled for 4 minutes and the distillate receive into a flask containing twenty ml of 4 % boric acid (H3BO3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change would be from pink to green after distillation, after which the content of the flask would be titrated with 0.02 M HCl from a burette. At the end-point when the solution changes from weak green to pink the volume of 0.02 M HCl would be recorded and % N calculated. A blank distillation and titration would also be carried out to take care of traces of nitrogen in the reagents as well as the water used. Calculation: The percentage nitrogen in the sample was expressed as: % N = ...eqn (2) 42 Where M = concentration of Hydrochloric acid used in titration a = volume of hydrochloric acid used in sample b = volume of hydrochloric acid used in blank S = weight of air – dry samples in grams mcf = moisture correction factor ....eqn (3)

Phosphorus (P)

The readily acid-soluble forms of phosphorus would be extracted with a HCl: NH4F mixture called the Bray's no.1 extract as described by Amuzu (2022) and Olsen and Sommers (1982). Phosphorus in the extract would be determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. Approximately 5 g of rice husk or faecal matter would be weighed into 100 ml extraction bottle and 35 ml of extracting solution of Bray's no. 1 (0.03M) NH4F in filtered through Whatman no.42 filter paper. The resulting clear solution would be collected into a 100 ml volumetric flask. An aliquot of about 5 ml of the clear supernatant solution would be pipetted into 25 ml test tube and 10 ml coloring reagent (ammonium paramolybdate) would be added as well as a pinch of ascorbic acid and then mixed very well. The mixture would be allowed to stand for 15 minutes to develop a blue colour to its maximum. The colour would be measured photometrically using a spectronic 21D spectrophotometer at

660 nm wavelength. Available phosphorus would be extrapolated from the absorbance read. A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l would be prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flask and make to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 43 6 ml of the 100 mg P/l of the standard solution would be put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water. Calculation: P (mg/kg) = ...eqn (4)

where; a = mg/l P in sample extract

b = mg/l P in blank

S = weight of air – dry samples in grams mcf = moisture correction factor...............................eqn(5) 35 = volume of extracting solution 15 = final volume of sample solution

Potassium (K)

Available potassium was extracted using the Bray's no. 1 solution which would be determined directly using the Gallenkamp flame analyzer. Available potassium concentration would be determined from the standard curve. Potassium standard solutions would be prepared with the following concentrations: 0, 10, 20, 30, and 50 µg K / ml of solution. The emission values would be read on the flame analyser. A standard curve would be obtained by plotting emission values against their respective concentrations.

Calculation: P (mg/kg) = ...eqn (6)

where; a = µgK/ml in sample extract

b = µgK/ml in blank S = weight of air – dry samples in grams 44

mcf = moisture correction factor 35 = volume of extracting solution

FLUORIDE EXTRACTION OF AVAILABLE P IN COMPOST

_REAGENTS

N HCl: Measure 87 ml of Conc. HCl (Sp. Gr. 1.18, 36%), and make up to 1000 ml in a volumetric flask.

V;blk/ BRAY 1 EXTRACTANT: (0.025 N HCl + 0.03N NH_4F): Dissolve 2.22 g NH_4F and 5.0 ml conc. HCl in deionized water and make up to 2 L in a volumetric flask.

1. AMMONIUM MOLYBDATE –HCl, BORIC ACID SATURATED SOLUTION:

a. Dissolve 37.652g of ammonium molybdate, $(HN_4)_6 M_{07}O_{24}. 4H_2 O$ in about 245 ml of distilled water, heating to 60^{o}C.
b. Cool and add to 781.5 ml conc. HCl.
c. Make up to the 1000 ml mark in a volumetric flask with deionized water
d. Store in a brown glass stoppered bottle containing 50 g boric acid (H_3PO_3).

2. ASCORBIC ACID: 1.76 g / 100 ml distilled water. Prepare fresh solution each day.
3. STOCK STANDARD A (2500 µg P/ml): Oven dry about 15 g of KH_2PO_4 (A.R. grade, M.W. = 136.09, 99.5%) at 80^o C for 2 hours. Weigh out 10.9825 g, dissolve and make up to 1 liter with distilled water.
4. WORKING STOCK STANDARD B IN BRAY 1 (250 µg P/ml): Pipette 25 ml of stock A into a clean 250 ml volumetric flask and make up to volume using Bray 1 extractant.
5. WORKING STANDARDS IN BRAY 1: Using 5 clean 250 volumetric flasks, pipette 0, 2, 4, 8, 12, 16 and 20 ml of stock B respectively into each flask. Make up to 250 ml using Bray 1 solution. The working standards contain respectively 0, 1, 2, 4, 6, 8 and 10 µg P/ml in 250 ml volumetric flasks.

PROCEDURE

1. Weigh 3 g of air-dry composr (2 mm sieved) into centrifuge tubes and add 15 ml of Bray 1 solution
2. Shake on a mechanical shaker for 5 minutes
3. Allow to stand for 2 mins and then centrifuge for 5 mins at 3000 rpm
4. Pipette 2 ml of the clear supernatant solution (sample) and /or the standard solutions into a set of clean centrifuge tubes
5. Add 10 ml of distilled water and mix well
6. Add 2 ml of color reagent and mix well again
7. Add 2 ml of ascorbic acid solution and mix thoroughly again
8. After 15 minutes measure the color at 650 nm on a colorimeter or visible range spectrophotometer
9. Plot absorbance verse ppm P. Read the unknown samples and obtain ppm P by interpolation on the graph C plotted.

Calculation

ppm P (µg P / kg soil) = C* 15/3

DETERMINATION OF AVAILABLE POTASSIUM BY AMMONIUM ACETATE IN THE COMPOST

1. EXTRACTING SOLUTION (1.0 N NH_4O Ac): - 57 ml of glacial acetic acid is diluted to 800 ml with distilled water. Neutralize solution with concentrated NH_4OH to pH 7.0. The solution is then diluted to one litre in a volumetric flask.

2. STANDARED K SOLUTION (1000 ppm (K):

For stock solution (1000 ppm K)

   1. Dissolve 1.907 g KCl (dried at 105^{o}C for 4 hours) in about 200 ml deionized water.
   2. Make up to 1000 ml with deionised water. This gives 100ppm (K).
   3. Dilute 50 ml of the 1000 ppm into 1000 ml to give 50 ppm for K.

0 ml of 50 ppm to 1000 ml = 0 ppm
4 ml = 2 ppm
8 = 4 ppm
12 = 6 ppm
16 = 8 ppm
20 = 10 ppm

PREPARATION OF COMPOST EXTRACT

1. Weigh 10 g of compost into extraction bottle.
2. Add 100 ml of 1.0 N NH_4OAc solution.
3. Place bottle with contents in a mechanical shaker and shake for 2 hours.
4. Filter the supernatant solution through No. 42 Whatman filter paper.
5. Take a 10 ml aliquot and read for K on a Flame Photometer after calibration of Photometer with prepared standards.

6. Determine the flame photometer reading for soil. Using the meter reading standard curve, determine the concentration of K in the soil extract.

Protocol for bacterial analysis

Sample Preparation

10.0g of the compost sample was weighed and added to 90ml of Peptone water and pulsified for 15sec.

1.0ml of the supernatant was taken for the serial dilutions.

Total and Faecal Coliforms

The Most Probable Number (MPN) method was used to determine tjr total and faecal coliforms in the compost samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1ml of the sample into 9ml sterile distilled water. 1ml aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth and incubated at 37°C for total coliforms and 44°C faecal coliforms for 18-24 hours. Tubes showing colour change from purple to yellow after 24hours were identified as positive for both total and faecal coliforms. Counts per 100ml were calculated from the MPN tables.

Composting Procedure (Mixing ratio)

Based on a preliminary analysis of the characteristics of both the faecal sludge and rice husk, four (4) different formulations of co-compost heaps were prepared from faecal sludge and rice husk. The ratios were rice husk to faecal sludge by volume, thus, 100% (90L) rice hush(control), 90L Rice husk to 45L faecal sludge, 90L Rice husk to 90L faecal sludge and 90L Rice husk to 180L faecal respectively .The treatments were in ratios 1:0, 1:0.5, 1:1, 1:2. Replication of each heap (‘a’ ‘b’ c’ and d’) were done, which means, every three heaps were having the same ratio. The heaps were prepared by measuring a total of 90L of both the rice husk and faecal sludge in their respective ratios. The composting heaps took average size of 2 m long, 1.5 m wide, and 0.6 m high piles. The mixtures were thoroughly mixed up with a shovel to obtain a uniform mixture. The heaps were then heaped in a windrow. Manual turning were adopted every seven days, as it is the commonest and less expensive method of composting organic wastes(Azis *et al*., 2022). During the composting period, three composite samples were taken from each composting pile at every turning. Each composite sample consisted of three sub-samples (about 1 kg each) were taken at 0.30–0.40 m depth. Approximately 20 g of each composite sample of the compost were used for assessing; OC, NPK (Total and available), EC, pH, C/N, Faecal and Total coliform

Temperature measurement

The temperature was measured daily at a different position within the compost (top, meddle and the bottom) for the first four weeks and twice every week for the following months because after fourth week the temperature begins to reduce for the compost to become more stable. The temperature will be measured using a thermocouple thermometer. Following the above procedure, the compost setups will be allowed to stay on composting site until compost maturity is completed and the composting experimental procedure is over.

Appendix B

Data analysis

ANOVA: NO_3-N

		Sum of Squares	df	Mean Square	F pr.(Sig.)
Day 0	Between Groups	30222.953	3	10074.318	<0.01
	Within Groups	74.513	8	9.314	
	Total	30297.467	11		
Day 30	Between Groups	1280240.757	3	426746.919	<0.01
	Within Groups	470.840	8	58.855	
	Total	1280711.597	11		
Day 60	Between Groups	2147853.340	3	715951.113	<0.01
	Within Groups	215.404	8	26.925	
	Total	2148068.743	11		
Day 90	Between Groups	5287430.280	3	1762476.760	<0.01
	Within Groups	245.490	8	30.686	
	Total	5287675.770	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple Comparison: NO_3-N

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig)
Day 0	Rice husk	RF(1:0.5)	-27.20000*	2.49188	< 0.01
		RF(1:1)	-102.16667*	2.49188	<0.01
		RF(1:2)	-120.36667*	2.49188	<0.01
	RF(1:0.5)	Rice husk	27.20000*	2.49188	<0.01
		RF(1:1)	-74.96667*	2.49188	<0.01
		RF(1:2)	-93.16667*	2.49188	<0.01
	RF(1:1)	Rice husk	102.16667*	2.49188	<0.01
		RF(1:0.5)	74.96667*	2.49188	<0.01
		RF(1:2)	-18.20000*	2.49188	<0.01
	RF(1:2)	Rice husk	120.36667*	2.49188	<0.01
		RF(1:0.5)	93.16667*	2.49188	<0.01
		RF(1:1)	18.20000*	2.49188	<0.01
Day 30	Rice husk	RF(1:0.5)	-462.33333*	6.26392	<0.01
		RF(1:1)	-469.66667*	6.26392	<0.01
		RF(1:2)	-923.80000*	6.26392	<0.01
	RF(1:0.5)	Rice husk	462.33333*	6.26392	<0.01
		RF(1:1)	-7.33333	6.26392	0.28
		RF(1:2)	-461.46667*	6.26392	<0.01
	RF(1:1)	Rice husk	469.66667*	6.26392	<0.01
		RF(1:0.5)	7.33333	6.26392	0.28
		RF(1:2)	-454.13333*	6.26392	<0.01
	RF(1:2)	Rice husk	923.80000*	6.26392	<0.01
		RF(1:0.5)	461.46667*	6.26392	<0.01
		RF(1:1)	454.13333*	6.26392	<0.01
Day 60	Rice husk	RF(1:0.5)	-506.83667*	4.23678	<0.01
		RF(1:1)	-1045.80333*	4.23678	<0.01
		RF(1:2)	-992.13667*	4.23678	<0.01
	RF(1:0.5)	Rice husk	506.83667*	4.23678	<0.01
		RF(1:1)	-538.96667*	4.23678	<0.01
		RF(1:2)	-485.30000*	4.23678	<0.01
	RF(1:1)	Rice husk	1045.80333*	4.23678	<0.01
		RF(1:0.5)	538.96667*	4.23678	<0.01
		RF(1:2)	53.66667*	4.23678	<0.01
	RF(1:2)	Rice husk	992.13667*	4.23678	<0.01
		RF(1:0.5)	485.30000*	4.23678	<0.01
		RF(1:1)	-53.66667*	4.23678	<0.01

Day 90	Rice husk	RF(1:0.5)	-630.93667*	4.52300	<0.01
		RF(1:1)	-1586.10333*	4.52300	<0.01
		RF(1:2)	-1544.90333*	4.52300	<0.01
	RF(1:0.5)	Rice husk	630.93667*	4.52300	<0.01
		RF(1:1)	-955.16667*	4.52300	<0.01
		RF(1:2)	-913.96667*	4.52300	<0.01
	RF(1:1)	Rice husk	1586.10333*	4.52300	<0.01
		RF(1:0.5)	955.16667*	4.52300	<0.01
		RF(1:2)	41.20000*	4.52300	<0.01
	RF(1:2)	Rice husk	1544.90333*	4.52300	<0.01
		RF(1:0.5)	913.96667*	4.52300	<0.01
		RF(1:1)	-41.20000*	4.52300	<0.01

* The mean difference is significant at F pr. Level of 0.05

ANOVA: NH_4-N

		Sum of Squares	df	Mean Square	F pr. (Sig.)
Day 0	Between Groups	982517.869	3	327505.956	<0.01
	Within Groups	568.740	8	71.093	
	Total	983086.609	11		
Day 30	Between Groups	2735768.082	3	911922.694	<0.01
	Within Groups	197.387	8	24.673	
	Total	2735965.469	11		
Day 60	Between Groups	4239985.869	3	1413328.623	<0.01
	Within Groups	1576.213	8	197.027	
	Total	4241562.082	11		
Day 90	Between Groups	8913484.250	3	2971161.417	<0.01
	Within Groups	2880.414	8	360.052	
	Total	8916364.664	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple Comparison: NH_4-N

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig.)
Day 0	Rice husk	RF(1:0.5)	-514.86667*	6.88440	<0.01
		RF(1:1)	-641.53333*	6.88440	<0.01
		RF(1:2)	-744.36667*	6.88440	<0.01
	RF(1:0.5)	Rice husk	514.86667*	6.88440	<0.01
		RF(1:1)	-126.66667*	6.88440	<0.01
		RF(1:2)	-229.50000*	6.88440	<0.01
	RF(1:1)	Rice husk	641.53333*	6.88440	<0.01
		RF(1:0.5)	126.66667*	6.88440	<0.01
		RF(1:2)	-102.83333*	6.88440	<0.01
	RF(1:2)	Rice husk	744.36667*	6.88440	<0.01
		RF(1:0.5)	229.50000*	6.88440	<0.01
		RF(1:1)	102.83333*	6.88440	<0.01
Day 30	Rice husk	RF(1:0.5)	-963.50000*	4.05572	<0.01
		RF(1:1)	-935.70000*	4.05572	<0.01
		RF(1:2)	-1276.36667*	4.05572	<0.01
	RF(1:0.5)	Rice husk	963.50000*	4.05572	<0.01
		RF(1:1)	27.80000*	4.05572	<0.01
		RF(1:2)	-312.86667*	4.05572	<0.01
	RF(1:1)	Rice husk	935.70000*	4.05572	<0.01
		RF(1:0.5)	-27.80000*	4.05572	<0.01
		RF(1:2)	-340.66667*	4.05572	<0.01
	RF(1:2)	Rice husk	1276.36667*	4.05572	<0.01
		RF(1:0.5)	312.86667*	4.05572	<0.01
		RF(1:1)	340.66667*	4.05572	<0.01
Day 60	Rice husk	RF(1:0.5)	-988.03333*	11.46085	<0.01
		RF(1:1)	-1474.36667*	11.46085	<0.01
		RF(1:2)	-1436.70000*	11.46085	<0.01
	RF(1:0.5)	Rice husk	988.03333*	11.46085	<0.01
		RF(1:1)	-486.33333*	11.46085	<0.01
		RF(1:2)	-448.66667*	11.46085	<0.01
	RF(1:1)	Rice husk	1474.36667*	11.46085	<0.01
		RF(1:0.5)	486.33333*	11.46085	<0.01

		RF(1:2)	37.66667*	11.46085	0.01
	RF(1:2)	Rice husk	1436.70000*	11.46085	<0.01
		RF(1:0.5)	448.66667*	11.46085	<0.01
		RF(1:1)	-37.66667*	11.46085	0.01
Day 90	Rice husk	RF(1:0.5)	-1710.00000*	15.49305	<0.01
		RF(1:1)	-2122.00000*	15.49305	<0.01
		RF(1:2)	-2042.33333*	15.49305	<0.01
	RF(1:0.5)	Rice husk	1710.00000*	15.49305	<0.01
		RF(1:1)	-412.00000*	15.49305	<0.01
		RF(1:2)	-332.33333*	15.49305	<0.01
	RF(1:1)	Rice husk	2122.00000*	15.49305	<0.01
		RF(1:0.5)	412.00000*	15.49305	<0.01
		RF(1:2)	79.66667*	15.49305	.001
	RF(1:2)	Rice husk	2042.33333*	15.49305	<0.01
		RF(1:0.5)	332.33333*	15.49305	<0.01
		RF(1:1)	-79.66667*	15.49305	.001

* The mean difference is significant at F pr. Level of 0.05

ANOVA: Mineralized P

		Sum of Squares	df	Mean Square	F pr. (Sig.)
Day 0	Between Groups	432895.442	3	144298.481	<0.01
	Within Groups	81.327	8	10.166	
	Total	432976.769	11		
Day 30	Between Groups	638875.750	3	212958.583	<0.01
	Within Groups	222.460	8	27.808	
	Total	639098.210	11		
Day 60	Between Groups	685400.756	3	228466.919	<0.01
	Within Groups	1031.553	8	128.944	
	Total	686432.309	11		
Day 90	Between Groups	118401.333	3	39467.111	<0.01
	Within Groups	43.333	8	5.417	
	Total	118444.667	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple Comparison: Mineralized P

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig.)
Day 0	Rice husk	RF(1:0.5)	-339.73333*	2.60331	<0.01
		RF(1:1)	-422.50000*	2.60331	<0.01
		RF(1:2)	-496.40000*	2.60331	<0.01
	RF(1:0.5)	Rice husk	339.73333*	2.60331	<0.01
		RF(1:1)	-82.76667*	2.60331	<0.01
		RF(1:2)	-156.66667*	2.60331	<0.01
	RF(1:1)	Rice husk	422.50000*	2.60331	<0.01
		RF(1:0.5)	82.76667*	2.60331	<0.01
		RF(1:2)	-73.90000*	2.60331	<0.01
	RF(1:2)	Rice husk	496.40000*	2.60331	<0.01
		RF(1:0.5)	156.66667*	2.60331	<0.01
		RF(1:1)	73.90000*	2.60331	<0.01
Day 30	Rice husk	RF(1:0.5)	-628.50000*	4.30562	<0.01
		RF(1:1)	-165.00000*	4.30562	<0.01
		RF(1:2)	-292.83333*	4.30562	<0.01
	RF(1:0.5)	Rice husk	628.50000*	4.30562	<0.01
		RF(1:1)	463.50000*	4.30562	<0.01
		RF(1:2)	335.66667*	4.30562	<0.01
	RF(1:1)	Rice husk	165.00000*	4.30562	<0.01
		RF(1:0.5)	-463.50000*	4.30562	<0.01
		RF(1:2)	-127.83333*	4.30562	<0.01
	RF(1:2)	Rice husk	292.83333*	4.30562	<0.01
		RF(1:0.5)	-335.66667*	4.30562	<0.01
		RF(1:1)	127.83333*	4.30562	<0.01
Day 60	Rice husk	RF(1:0.5)	-163.20000*	9.27161	<0.01
		RF(1:1)	-589.43333*	9.27161	<0.01
		RF(1:2)	-490.93333*	9.27161	<0.01
	RF(1:0.5)	Rice husk	163.20000*	9.27161	<0.01
		RF(1:1)	-426.23333*	9.27161	<0.01
		RF(1:2)	-327.73333*	9.27161	<0.01
	RF(1:1)	Rice husk	589.43333*	9.27161	<0.01
		RF(1:0.5)	426.23333*	9.27161	<0.01
		RF(1:2)	98.50000*	9.27161	<0.01

	RF(1:2)	Rice husk	490.93333*	9.27161	<0.01
		RF(1:0.5)	327.73333*	9.27161	<0.01
		RF(1:1)	-98.50000*	9.27161	<0.01
Day 90	Rice husk	RF(1:0.5)	40.66667*	1.90029	<0.01
		RF(1:1)	40.00000*	1.90029	<0.01
		RF(1:2)	-199.33333*	1.90029	<0.01
	RF(1:0.5)	Rice husk	-40.66667*	1.90029	<0.01
		RF(1:1)	-.66667	1.90029	0.74
		RF(1:2)	-240.00000*	1.90029	<0.01
	RF(1:1)	Rice husk	-40.00000*	1.90029	<0.01
		RF(1:0.5)	.66667	1.90029	0.74
		RF(1:2)	-239.33333*	1.90029	<0.01
	RF(1:2)	Rice husk	199.33333*	1.90029	<0.01
		RF(1:0.5)	240.00000*	1.90029	<0.01
		RF(1:1)	239.33333*	1.90029	<0.01

* The mean difference is significant at F pr. Level of 0.05

ANOVA: Mineralized K

		Sum of Squares	df	Mean Square	F pr. (Sig.)
Day 0	Between Groups	4342396.743	3	1447465.581	<0.01
	Within Groups	1126.760	8	140.845	
	Total	4343523.503	11		
Day 30	Between Groups	2206248.293	3	735416.098	<0.01
	Within Groups	376.693	8	47.087	
	Total	2206624.987	11		
Day 60	Between Groups	7673312.667	3	2557770.889	<0.01
	Within Groups	224.000	8	28.000	
	Total	7673536.667	11		
Day 90	Between Groups	1021262.917	3	340420.972	<0.01
	Within Groups	297.333	8	37.167	
	Total	1021560.250	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple Comparison: Mineralized K

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig.)
Day 0	Rice husk	RF(1:0.5)	-1301.93333*	9.69003	<0.01
		RF(1:1)	-1385.50000*	9.69003	<0.01
		RF(1:2)	-1461.80000*	9.69003	<0.01
	RF(1:0.5)	Rice husk	1301.93333*	9.69003	<0.01
		RF(1:1)	-83.56667*	9.69003	<0.01
		RF(1:2)	-159.86667*	9.69003	<0.01
	RF(1:1)	Rice husk	1385.50000*	9.69003	<0.01
		RF(1:0.5)	83.56667*	9.69003	<0.01
		RF(1:2)	-76.30000*	9.69003	<0.01
	RF(1:2)	Rice husk	1461.80000*	9.69003	<0.01
		RF(1:0.5)	159.86667*	9.69003	<0.01
		RF(1:1)	76.30000*	9.69003	<0.01
Day 30	Rice husk	RF(1:0.5)	-1198.06667*	5.60278	<0.01
		RF(1:1)	-456.40000*	5.60278	<0.01
		RF(1:2)	-626.06667*	5.60278	<0.01
	RF(1:0.5)	Rice husk	1198.06667*	5.60278	<0.01
		RF(1:1)	741.66667*	5.60278	<0.01
		RF(1:2)	572.00000*	5.60278	<0.01
	RF(1:1)	Rice husk	456.40000*	5.60278	<0.01
		RF(1:0.5)	-741.66667*	5.60278	<0.01
		RF(1:2)	-169.66667*	5.60278	<0.01
	RF(1:2)	Rice husk	626.06667*	5.60278	<0.01
		RF(1:0.5)	-572.00000*	5.60278	<0.01
		RF(1:1)	169.66667*	5.60278	<0.01

Day 60	Rice husk	RF(1:0.5)	-16.33333*	4.32049	<0.01
		RF(1:1)	-1520.66667*	4.32049	<0.01
		RF(1:2)	-1685.66667*	4.32049	<0.01
	RF(1:0.5)	Rice husk	16.33333*	4.32049	<0.01
		RF(1:1)	-1504.33333*	4.32049	<0.01
		RF(1:2)	-1669.33333*	4.32049	<0.01
	RF(1:1)	Rice husk	1520.66667*	4.32049	<0.01
		RF(1:0.5)	1504.33333*	4.32049	<0.01
		RF(1:2)	-165.00000*	4.32049	<0.01
	RF(1:2)	Rice husk	1685.66667*	4.32049	<0.01
		RF(1:0.5)	1669.33333*	4.32049	<0.01
		RF(1:1)	165.00000*	4.32049	<0.01
Day 90	Rice husk	RF(1:0.5)	-279.00000*	4.97773	<0.01
		RF(1:1)	-407.66667*	4.97773	<0.01
		RF(1:2)	-810.33333*	4.97773	<0.01
	RF(1:0.5)	Rice husk	279.00000*	4.97773	<0.01
		RF(1:1)	-128.66667*	4.97773	<0.01
		RF(1:2)	-531.33333*	4.97773	<0.01
	RF(1:1)	Rice husk	407.66667*	4.97773	<0.01
		RF(1:0.5)	128.66667*	4.97773	<0.01
		RF(1:2)	-402.66667*	4.97773	<0.01
	RF(1:2)	Rice husk	810.33333*	4.97773	<0.01
		RF(1:0.5)	531.33333*	4.97773	<0.01
		RF(1:1)	402.66667*	4.97773	<0.01

* The mean difference is significant at F pr. Level of 0.05

ANOVA: pH

		Sum of Squares	df	Mean Square	F pr.(Sig.)
Day 0	Between Groups	1.350	3	.450	<0.01
	Within Groups	.080	8	.010	
	Total	1.430	11		
Day 30	Between Groups	.525	3	.175	<0.01
	Within Groups	.089	8	.011	
	Total	.614	11		

Day 60	Between Groups	.080	3	.027	<0.01
	Within Groups	.002	8	.000	
	Total	.082	11		
Day 90	Between Groups	.180	3	.060	<0.01
	Within Groups	.001	8	.000	
	Total	.181	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple comparison: pH

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig.)
Day 0	Rice husk	RF(1:0.5)	-.60000*	.08165	<0.01
		RF(1:1)	-.70000*	.08165	<0.01
		RF(1:2)	-.90000*	.08165	<0.01
	RF(1:0.5)	Rice husk	.60000*	.08165	<0.01
		RF(1:1)	-.10000	.08165	0.26
		RF(1:2)	-.30000*	.08165	0.01
	RF(1:1)	Rice husk	.70000*	.08165	<0.01
		RF(1:0.5)	.10000	.08165	0.26
		RF(1:2)	-.20000*	.08165	0.04
	RF(1:2)	Rice husk	.90000*	.08165	<0.01
		RF(1:0.5)	.30000*	.08165	0.01
		RF(1:1)	.20000*	.08165	0.04
Day 30	Rice husk	RF(1:0.5)	-.01333	.08612	0.88
		RF(1:1)	-.31000*	.08612	0.01
		RF(1:2)	-.49667*	.08612	<0.01
	RF(1:0.5)	Rice husk	.01333	.08612	0.88
		RF(1:1)	-.29667*	.08612	0.01
		RF(1:2)	-.48333*	.08612	0.01
	RF(1:1)	Rice husk	.31000*	.08612	0.01
		RF(1:0.5)	.29667*	.08612	0.01
		RF(1:2)	-.18667	.08612	0.06
	RF(1:2)	Rice husk	.49667*	.08612	<0.01
		RF(1:0.5)	.48333*	.08612	<0.01
		RF(1:1)	.18667	.08612	0.06
Day 60	Rice husk	RF(1:0.5)	-.40333*	.00972	<0.01
		RF(1:1)	-.50000*	.00972	<0.01
		RF(1:2)	-.30333*	.00972	<0.01
	RF(1:0.5)	Rice husk	.40333*	.00972	<0.01
		RF(1:1)	-.09667*	.00972	<0.01
		RF(1:2)	.10000*	.00972	<0.01
	RF(1:1)	Rice husk	.50000*	.00972	<0.01
		RF(1:0.5)	.09667*	.00972	<0.01
		RF(1:2)	.19667*	.00972	<0.01
	RF(1:2)	Rice husk	.30333*	.00972	<0.01
		RF(1:0.5)	-.10000*	.00972	<0.01
		RF(1:1)	-.19667*	.00972	<0.01
Day 90	Rice husk	RF(1:0.5)	-.30000*	.00943	<0.01

		RF(1:1)	-.19333*	.00943	<0.01
		RF(1:2)	-.30000*	.00943	<0.01
	RF(1:0.5)	Rice husk	.30000*	.00943	<0.01
		RF(1:1)	.10667*	.00943	<0.01
		RF(1:2)	.00000	.00943	1.00
	RF(1:1)	Rice husk	.19333*	.00943	<0.01
		RF(1:0.5)	-.10667*	.00943	<0.01
		RF(1:2)	-.10667*	.00943	<0.01
	RF(1:2)	Rice husk	.30000*	.00943	<0.01
		RF(1:0.5)	.00000	.00943	1.00
		RF(1:1)	.10667*	.00943	<0.01

* The mean difference is significant at F pr. Level of 0.05

ANOVA: Electrical conductivity

		Sum of Squares	df	Mean Square	F pr. (Sig.)
Day 0	Between Groups	33.924	3	11.308	<0.01
	Within Groups	.012	8	.001	
	Total	33.936	11		
Day 30	Between Groups	8.218	3	2.739	<0.01
	Within Groups	.003	8	.000	
	Total	8.220	11		
Day 60	Between Groups	1.940	3	.647	<0.01
	Within Groups	.007	8	.001	
	Total	1.948	11		
Day 90	Between Groups	34.554	3	11.518	<0.01
	Within Groups	.003	8	.000	
	Total	34.556	11		

* The mean difference is significant at F pr. Level of 0.05

LSD Multiple comparison: Electrical Conductivity

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	F pr. (Sig.)
Day 0	Rice husk	RF(1:0.5)	-1.45667*	.03162	<0.01

		RF(1:1)	-3.67333*	.03162	<0.01
		RF(1:2)	-4.15000*	.03162	<0.01
	RF(1:0.5)	Rice husk	1.45667*	.03162	<0.01
		RF(1:1)	-2.21667*	.03162	<0.01
		RF(1:2)	-2.69333*	.03162	<0.01
	RF(1:1)	Rice husk	3.67333*	.03162	<0.01
		RF(1:0.5)	2.21667*	.03162	<0.01
		RF(1:2)	-.47667*	.03162	<0.01
	RF(1:2)	Rice husk	4.15000*	.03162	<0.01
		RF(1:0.5)	2.69333*	.03162	<0.01
		RF(1:1)	.47667*	.03162	<0.01
Day 30	Rice husk	RF(1:0.5)	-.82000*	.01472	<0.01
		RF(1:1)	-.87000*	.01472	<0.01
		RF(1:2)	-2.30000*	.01472	<0.01
	RF(1:0.5)	Rice husk	.82000*	.01472	<0.01
		RF(1:1)	-.05000*	.01472	<0.01
		RF(1:2)	-1.48000*	.01472	<0.01
	RF(1:1)	Rice husk	.87000*	.01472	<0.01
		RF(1:0.5)	.05000*	.01472	<0.01
		RF(1:2)	-1.43000*	.01472	<0.01
	RF(1:2)	Rice husk	2.30000*	.01472	<0.01
		RF(1:0.5)	1.48000*	.01472	<0.01
		RF(1:1)	1.43000*	.01472	<0.01
Day 60	Rice husk	RF(1:0.5)	-.18000*	.02494	<0.01
		RF(1:1)	-.55667*	.02494	<0.01
		RF(1:2)	-1.05000*	.02494	<0.01
	RF(1:0.5)	Rice husk	.18000*	.02494	<0.01
		RF(1:1)	-.37667*	.02494	<0.01
		RF(1:2)	-.87000*	.02494	<0.01
	RF(1:1)	Rice husk	.55667*	.02494	<0.01
		RF(1:0.5)	.37667*	.02494	<0.01
		RF(1:2)	-.49333*	.02494	<0.01
	RF(1:2)	Rice husk	1.05000*	.02494	<0.01
		RF(1:0.5)	.87000*	.02494	<0.01
		RF(1:1)	.49333*	.02494	<0.01
Day 90	Rice husk	RF(1:0.5)	-2.42000*	.01472	<0.01
		RF(1:1)	-3.91000*	.01472	<0.01
		RF(1:2)	-4.34000*	.01472	<0.01

	RF(1:0.5)	Rice husk	2.42000^{*}	.01472	<0.01
		RF(1:1)	-1.49000^{*}	.01472	<0.01
		RF(1:2)	-1.92000^{*}	.01472	<0.01
	RF(1:1)	Rice husk	3.91000^{*}	.01472	<0.01
		RF(1:0.5)	1.49000^{*}	.01472	<0.01
		RF(1:2)	$-.43000^{*}$	.01472	<0.01
	RF(1:2)	Rice husk	4.34000^{*}	.01472	<0.01
		RF(1:0.5)	1.92000^{*}	.01472	<0.01
		RF(1:1)	$.43000^{*}$	.01472	<0.01

* The mean difference is significant at F pr. Level of 0.05