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MANAGEMENT PRACTICES OF MAJOR AGRICULTURAL WASTES AND THEIR IMPACT ON DECOMPOSITION AND MINERALIZATION: A CASE STUDY OF KWAEBIBIREM DISTRICT, GHANA

BY

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DECLARATION

I, Photide Mukandayambaje hereby declare that this thesis entitled "Assessment of management practices of major agricultural wastes and its impact on decomposition and mineralization: a case study of Kwaebibirem District, Ghana" except for the references that have been duly acknowledged is an original work carried out entirely by me under the supervision of Dr. Ted Yemoh Annang and Prof. Godfred K. Ofosu-Budu, University of Ghana. I confirm that this thesis has neither in whole nor in part been presented for another degree elsewhere.

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DEDICATION

This work is dedicated to the Almighty God and our Lord and Savior Jesus Christ, Amen.

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ABSTRACT

Significant quantities of agricultural and agro-industrial wastes are produced annually. Improper management of these wastes poses environmental problems such as surface and ground water pollution and air pollution among others. Managing agricultural wastes aim at maximizing economic benefits from the waste resources with affordable, suitable and environmental friendly systems. The aim of this study was to assess the current management practices of major agricultural wastes generated and evaluate the impact of some of these wastes on decomposition, mineralization as well as carbon dioxide and ammonia emissions. Questionnaires were administered to 175 farmers from five communities in the Kwaebibirem District. Five laboratory experiments were also conducted; effect of organic residue type and particle size on CO_2 emission was investigated during 120 days; effect of organic residue type and particle size on decomposition and nutrient release patterns were evaluated during 22 weeks; CO_2 and NH_3 emissions from poultry droppings as affected by biochar application at different pH and rates were separately assessed during 30 days and the effect of biochar application to poultry droppings on nutrients release was assessed during 30 days. The findings of the study indicated that the major agricultural wastes of concern generated in the Kwaebibirem District were crop residues and animal wastes. The most crop residues generated were cocoa pod husks (CPH); various wastes from palm fruits, mainly empty fruit bunches (EFB); rice husks (RH) and straws and corn stalks. Animal wastes generated were predominantly poultry droppings (PD). The results indicated that the farmers have inadequate knowledge on the sustainable management of agricultural wastes and their uses in terms of soil fertility improvement. It is also revealed that farmers perceive weakly in animal manure use in soil fertility improvement. The results indicated that the cumulative CO_2 emissions of EFB and CPH were not statistically different except for the smallest particle sizes, CPHS3 significantly emitted higher CO_2 than EFBS3. The particle size of EFB and CPH significantly affected the cumulative CO_2 emission. The cumulative CO_2 emissions from EFB increased in the order of EFBS1<EFBS2< EFBS3 and their corresponding average cumulative CO_2 emitted was 310.95, 326.04 and 350.70 mg CO_2/g residue, respectively. The cumulative CO_2 emissions from CPH increased in the order of CPHS1<CPHS2< CPHS3 and their corresponding average cumulative CO_2 emitted was 313.55, 337.73 and 366.04 mg CO_2/g residue, respectively. Results showed that CPH decomposed faster than EFB throughout the incubation period even if the difference was not statistically significant. The nutrients in EFB and CPH particle sizes were released in the order K> Ca > P = N at different rates. There was no significant difference in N and P release in EFB and CPH. CPH released K and Ca faster than EFB of the same particle size. Particle size of each of EFB and CPH did not show significance difference in release nutrients at the end of incubation period except for P release in CPH, where CPHS3 released significantly higher amount of P than CPHS1 and CPHS2. Results showed that irrespective of biochar rates and pH, mixing of biochar and poultry droppings resulted in a highly significant reduction ($p<0.001$) of CO_2 and NH_3 emissions. Biochar was effective in reducing over 30% of CO_2 and 20% of NH_3 emitted by poultry droppings alone. Biochar at pH6 was most effective in reducing CO_2 and NH_3 emissions. It was indicated that application of biochar to poultry droppings reduced nutrients release rate. The study highly recommends education and the trainings for the farmers on the impact of agro industrial wastes to the environment, affordable and environmental friendly management practices. Both EFB and CPH are suited for soil organic matter build-up and chopping the residues in small particle sizes is advised for short term fertility purpose. Biochar should be added to poultry droppings to retain nutrients, reduce carbon dioxide and ammonia gases emissions as a waste management strategy to reduce as well.

LIST OF ABREVIATIONS AND ACRONYMS

ADF	Acid detergent fiber
ARISE II	Africa Regional International Staff/Student Exchange II
BNARI	Biotechnology and Nuclear Agriculture Research Institute
C	Carbon
Ca	Calcium
CO_2	Carbon dioxide
CPH	Cocoa pod husks
DM	Dry matter
EFB	Empty fruit bunches
FAO	Food and Agriculture Organization
GAE	Gallic acid equivalent
GAEC	Ghana Atomic Energy Commission
GHG	Greenhouse gases
HCl	Hydrochloric acid
IPCC	Intergovernmental Panel on Climate Change
ISSER	Institute for Statistical, Social and Economic Research
K	Potassium
LIPREC	Livestock and Poultry Research Center
Mg	Magnesium
N	Nitrogen
NaOH	Sodium Hydroxide

NH_3	Ammonia
ORM_4Soil	Farmer-Driven Organic Resource Management for improvement of Soil fertility
P	Phosphorus
PD	Poultry droppings
pH	Potential of Hydrogen
PVC	Polyvinyl chloride
RHB	Rice husks biochar
SESRC	Soil and Environmental Sciences Research Centre
SOM	Soil Organic Matter
USDA	United States Department of Agriculture

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The utmost objective of all agricultural systems is the efficient production of food in abundance and high nutritional quality at a reasonable cost, while causing minimal interruption to the environment (Aronsson, Torstensson, & Bergstro, 2007). Tropical soil quality maintenance for sustainable agriculture is a challenge and the development of an efficient nutrient management technique is important (Das, Pal, & Bhattacharyya, 2012). The use of mineral fertilizers to address soil infertility in Sub Saharan Africa is limited due to economic constraints of farmers and availability at the right time (Walpola & Wanniarachchi, 2009), additionally, regular use of chemical fertilizers results in nutrient imbalances and environmental concerns thereby deteriorating soil productivity sustenance (Dey *et al*., 2019). Crops produced by organic fertilizers have superior quality and higher value than the crops produced by inorganic fertilizers because the former is free of synthetic chemicals (Olumuyiwatogun, Akanbi, & Adediran, 2004).

Agriculture or food production generates large quantities of wastes into the environment. These organic wastes contain plant nutrients in varying concentrations distributed and naturally recycled in the production areas. Sustainable agriculture dwells on recycling of organic resources within the same ecosystem to promote food production. The use of these organic resources from plant and animal residues in improving soil fertility for food production has attracted much attention in many countries.

These organic residues contain plant nutrients, provide organic matter for soil microbes, improve soil structure and health among others (Haney, Brinton, & Evans, 2008). These organic residues may improve soil physical, chemical and biological properties by building and maintaining soil organic matter (Haney, Brinton, & Evans, 2008; Shakoor *et al*., 2020).

Many organic residues are locally available, reducing the cost and environmental impacts of transportation, hence, land application of these organic residues reduces the burden to landfills, prevent the need to incinerate wastes and interestingly sequester carbon in the soil (Long & Brown, 2017). In Ghana, the most common locally available organic resources include farm products like cocoa pod husks, empty fruit bunches, straws and husks of cereals, stovers, leaves and pods of leguminous plants, fruit and vegetable residues, poultry manure, cow dung and pig manure (Tetteh., 2017).

It is the physical nature and biochemical composition of the organic residue that determine the quality and suitability as soil amendment (Bending & Turner, 1999). Soil type, moisture and temperature, organic amendments characteristics and microbial activity in the soil influence the mineralization activity (Dey *et al*., 2019). During decomposition, the decomposers constantly take up exogenous nutrients from their environment to strengthen their biomass (immobilization). Immobilization is the conversion of inorganic form into organic form by microorganism by incorporating mineral ions to synthesize cellular components (Palm & Saschez, 1990) and release nutrients from organic matter breakdown and biomass turnover (mineralization). Mineralization is the conversion of complex organic minerals into simpler inorganic form by different microorganisms (Morachan, 1972). Typically, organic residues quality variables of interest include lignin, soluble C, soluble phenolic, various cellulose fractions as well as nutrients content (Bridgham & Ye, 2013).

Suitable management strategies are required in the utilization of agricultural wastes in the soil in order to uphold crop production and protect the environment (Grzyb *et al*., 2020).

Composting and biochar production are the most flexible, cheaper and environmentally friendly organic waste management strategies. Biochar has the potential to sequester carbon, improve water and nutrient retention (Sieng-Huat, Bachmann, Zainal, & Cheong, 2019). Application of the organic residues especially composted materials and biochar are examples of climate-smart soil management strategies which might contribute in lowering carbon dioxide emissions from the soil due to their slower decomposition (Hossain *et al*., 2017). Soil CO_2 respiration has been used to determine the relative fertility of various soils (Haney, Brinton, & Evans, 2008).

Carbon sequestration: ‘‘The long-term storage of carbon in soils, vegetation, oceans and geological formations” (Kowalska *et al*., 2020) is an essential requirement for preserving soil organic matter (SOM), which serves as a source of plant nutrients as well as a potential CO_2 sink (Hossain *et al*., 2017; Munera *et al*., 2020). Soil characteristics, the environment, and land management all influence CO_2 exchange between soil and atmosphere (Hassouna *et al*., 2017; Söderqvist, 2019). The rate of soil carbon emission is strongly influenced by the amount and characteristics of additional organic materials, soil processes, and climatic factors, particularly temperature and water availability (Agehara & Warncke, 2005).

Regardless of the availability of various organic residues, there is less scientific basis for advising farmers on the appropriate time, rate, size and mode of application of the available organic residues in order to regulate the release of nutrients to the crop's nutrient requirements.

1.2 Problem statement

Expansion of agricultural production has generated significant quantities of animal wastes, agricultural crop residues and by-products from the agro-industrial sector (Obi, Ugwuishiwu, & Nwakaire, 2016). A large amount of these wastes are left to rot or dumped in open lands or incinerated. Improper disposal of the wastes could lead to environmental concerns such as soil degradation due to potassium and phosphorus loading, water quality impairment due to nitrogen and phosphorous loading, air quality impairment due to greenhouse gas emissions and bad odor gases such as hydrogen sulfide (H_2S) and volatile organic compounds (VOC_S).

Agricultural wastes contain beneficial materials to humans although the cost of collecting, transporting and processing these wastes is higher than the economic values but worth it as it provides avenues for managing the wastes which has become a big issue in recent years for ecological agriculture and sustainable development. Tropical countries including Ghana are facing problem of declining in soil fertility; due to high cost of chemical fertilizers, gradual deterioration of soil and other associated adverse impacts on the environment. The use of organic fertilizers in agriculture is an alternative sustainable way of food production. However, inappropriate use of organic wastes can also cause environmental problems including the impairment of air quality due to greenhouse gas emissions and nutrient leaching (Liu *et al*., 2020). Ammonia volatilization from agriculture cause environmental problems, additionally, it is one of the ways of nitrogen loss from the soil which cause economic loss (Mandal *et al*., 2016).

In the Kwaebibirem District, Eastern region of Ghana; Livestock farming, the cultivation of food and plantation crops and their processing results in the generation of large amounts of agricultural and agro-industrial wastes and much of it are mismanaged (Adamtey, 2005).

The rates of decomposition, nutrient release patterns of crop residues and associated greenhouse gas emissions are important information for designing a system for achieving nutrient synchronization leading to better utilization of plant nutrients and reduction of nutrients loss. Currently, farmers have less information on the use of these organic residues to improve soil fertility. For the effective and sustainable incorporation of agricultural wastes as source of plant nutrients, farmers need to know the application practices suitable for good yield achievement with minimal environmental concerns. There is need for research efforts on the suitability of different agricultural wastes as fertilizer, for optimum and sustainable development of crops.

Application of the organic residues especially biochar can be considered as climate-smart soil management practices that might help in reducing carbon dioxide (CO_2) emission from soil due to its slower decomposition (Hossain *et al*., 2017). Carbon sequestration is the prime requirement to conserve soil organic matter not only as source of plant nutrients but also to act as a potential sink of atmospheric CO_2 (Munera *et al*., 2020). Tropical soil quality maintenance for sustainable agriculture is a challenge and the development of an efficient nutrient management technique is important, thus, it is important to understand the decomposition and nutrient release patterns of these organic residues for better fertility management. The potential use of organic wastes in agriculture depends on several parameters and few of them have been studied. Therefore, this study aimed at assessing the management practices of major agricultural wastes and evaluating the impact of some of them on decomposition and mineralization and emissions of carbon dioxide and ammonia.

1.3 Objectives

1.3.1 General objective

The general objective of this study was to assess the current management practices of major agricultural wastes and evaluate the impact of some of these wastes on decomposition and mineralization, as well as Carbon dioxide (CO_2) and Ammonia (NH_3) emissions.

1.3.2 Specific objectives

Specifically, the study aimed at the following specific objectives to achieve the general objective.

(1) To determine major agricultural wastes generated within the study area and their management practices or uses by farmers

(2) To assess the effect of organic residues type and particle size on carbon dioxide (CO_2) emission

(3) To assess the effect of organic residues type and particle size on decomposition and nutrient release

(4) To assess the effect of biochar application to poultry droppings on nutrients release, carbon dioxide (CO_2) and ammonia (NH_3) emissions

(5) To evaluate farmer's knowledge and perception on the sustainable management of agricultural wastes

1.4 Justification of the study

The application of locally available and inexpensive agro-industrial wastes by both rural and urban farmers assures sustainable production, enhanced crop nutrition as well as environmental impact reduction or mitigation (Embrandiri *et al*, 2012). Inappropriate use of organic residues can cause environmental problems including the impairment of air quality due to greenhouse gas emissions and nutrient leaching (Liu *et al*., 2020).

Currently, researchers are focusing on the shift from waste disposal to the reusing of the wastes, with soil amendment being among the most effective and sustainable option (Sarkar *et al*., 2020). The high prices of inorganic fertilizers and the environmental concerns associated with their use have resulted in intensified studies into locally, inexpensive and environmentally friendly organic resources like crop residues, animal wastes and other organic wastes (Ayamba *et al*., 2021).

The beneficial effects of using agricultural residues in soil fertility improvement has been widely reported (Xu, 2005; Zhang *et al*., 2012; Partey, Preziosi, & Robson, 2014). The decomposition and succeeding release of nutrients in soil can be influenced by a number of factors, including physicochemical nature of the crop residues and amount (Johnson *et al*., 2007), soil characteristics (Chen *et al*., 2018) and environmental factors (Tian *et al*., 2007). The present study assessed the effect of particle size of crop residues on decomposition and mineralization. Diverse effect of the particle size of crop residues incorporated into the soil on decomposition and mineralization has been reported in the literature (Angers & Recous, 1997; Bending & Turner, 1999; Singh, Rengel, & Bowden, 2004). It is, however, not known how empty fruit bunches and cocoa pod husks and their particle sizes would affect decomposition and mineralization after application to the soil surface.

Use of animal manure in crop production is associated with environmental concerns including the emissions of greenhouse gases. Biochar has been reported to lower ammonia, carbon dioxide and other GHG emissions when used in co-composting of poultry droppings (Yemisi *et al*., 2019; Steiner, Melear, Harris, & Das, 2011).

However, there is little information on the effect of biochar application with poultry droppings either to reduce carbon dioxide or ammonia emission to the environment prior to use in soil fertility management for crop production. Furthermore, the pH of the biochar is known to affect its chemical properties (Esfandbod *et al*., 2017; Li *et al*., 2014) and its effect on nutrient release patterns, carbon dioxide and ammonia release when mixed with poultry droppings is not clear from the previous reported studies.

It is beneficial to investigate the current management practices of major agricultural wastes generated and study their decomposition, mineralization patterns and emissions of pollutant gases to enable knowledge on the efficient and environmental friendly practices of using agricultural wastes in improving the soil nutrients and emitting less greenhouse gases. The outcomes will be useful in selection of organic residue inputs with respect to nutrients mineralization.

The study will help researchers and agricultural extension officers better understand the farmer's approach on the sustainable management of agricultural wastes, hence promote subsequent efforts to integrate local farmers' knowledge with scientific knowledge. The existence of such scientific study in the Kwaebibirem District would serve as a decision support tool, for both state and private agencies, tasked to respond to improper management of agricultural wastes in the district and the whole country as well.

CHAPTER TWO

LITERATURE REVIEW

This chapter comprises the review of existing literature related to my study, focusing on the definition of terminologies and conceptual explanations, existing knowledge/research findings of studies related to my study and other empirical studies supporting my research. The review discussed the challenges and opportunities associated with agricultural wastes and the potential of agricultural wastes as soil amendments. The review was aimed at identifying gaps that provided the basis for the research questions of this study.

2.1 Agricultural wastes and their impact on the environment

Agricultural wastes are defined as ‘‘wastes associated with the production and processing of food and fiber on farms, feedlots, ranches, ranges, and forests which may include animal manure, crop residues, and dead animals’’ (Quartey & Chýlková, 2013). Similar to other activities of development, agriculture also is a major source of waste generation and environmental pollutions. Agriculture is a major contributor of land resources and water pollution (Nagendran, 2011).

In Ghana, large amounts of agricultural wastes are generated and most of these wastes remained unused and ultimately managed inappropriately. Ghana produces approximately 4.2 million tons of agricultural residues each year (Quartey & Chýlková, 2013). The common agricultural waste management practice in Ghana is the burning of the wastes (Nuhu *et al*., 2012). Burning agricultural wastes is associated with the release of particulate matter and greenhouse gases which negatively impact human health and the environment (Sarkar *et al*., 2020).

2.1.1 Agricultural wastes materials generation in Ghana

2.1.1.1 Empty fruit bunches (EFB) and quantity generated in Ghana

About 3,135,000 metric tons of oil palm fruits are produced in Ghana each year (Gbenatey *et al*., 2017). Empty fruit bunches are generated from the processing of the fresh fruit bunch (FFB) of oil palm in processing mills to produce palm oil and palm kennel oil. The exponential growth of oil palm industry has led to increased amount of wastes products from oil palm industry, especially empty fruit bunches (EFB) which is produced in large quantities. Empty fruit bunches, which accounts for 22% of the oil palm fresh fruits, is the most significant solid waste generated throughout the palm oil milling process (Zaharah & Lim, 2000; Osei-Amponsah *et al*., 2012).

Large quantities of EFB are disposed mostly by means of dumping on roadsides and incineration, which pose threats to the environment (Nuhu *et al*., 2012). Empty fruit bunches contain polyphenols (a variety of phenolic acids) (Naim, Yahaya, & Edyvean, 2017; Hafyan *et al*., 2020). The cell wall of EFB commonly contains 25%, 50% and 25% of lignin, cellulose and hemicellulose respectively (Kavitha, Jothimani, & Rajannan, 2013). It also contains inorganic elements and small depositions of wax (Nazir *et al*., 2013).

2.1.1.2 Cocoa pod husks (CPH) and quantity generated in Ghana

Cocoa (*Theobroma cacao*) is an economic crop in Ghana and produced in high quantities. Ghana produces approximately 400,000 tonnes of cocoa beans (Gbenatey *et al*., 2017). Cocoa pod husk is the principal by-product of cocoa beans, accounting for around 75% of the total weight of the fruit (Lu *et al*., 2018). Cocoa pod husks as a potential source of organic fertilizer are ignored and disposed as wastes (Kayode *et al*., 2018; Mensah *et al*., 2018). Though CPH have been being used for traditional soap and animal feed production, the majority are unmindful of its improvement effects on nutrient-depleted soils. Cocoa pod husk is a potential source of potassium (Agyarko & Asiedu, 2012) and rich in fiber (lignin, cellulose, hemicellulose and pectin) and polyphenols (Lu *et al*., 2018).

2.1.1.3 Rice husks and quantity generated in Ghana

Rice is a staple food in the diets of many countries worldwide including Ghana which currently produces 575,000 metric tonnes annually (Offei *et al*., 2011). However, the generation of the waste in the rice production chain is ignored after harvesting and milling. The residue-to-product ratio (RPR) for rice, which refers to the ratio of the rice paddy to the other components of the rice is 0.2 for rice husks (Offei *et al*., 2011). Approximately, 146,186.2 tonnes of rice husks per annum are produced in Ghana. These contained N, P, and K elements with nutrient equivalent (in tons) of 2,530 N, 990 P2O5, and 5,460 K2O, respectively (Tobita & Issaka, 2011).

It is more difficult to manage rice husks compared to other wastes generated by rice production because rice husks are primarily generated at rice mills, quite located to a distance from the fields (Amponsem & Ojeh, 2017). Hence, their use in soil fertilization is less prominent. The burning of rice husks in large heaps is the most common rice husks management practice practiced by many rice mills. This leads to the emissions of large quantities of greenhouse gases, especially carbon dioxide in the atmosphere (Syuhadah & Rohasliney, 2011).

2.1.1.4 Poultry droppings and quantity generated in Ghana

The increase demand of animal proteins has resulted in the expansion of poultry industry with its attendant waste generation such as poultry droppings and litter which needs attention in management. In Ghana, current estimates put the chicken population at 74.5 million and generates around 740,000 tons of poultry droppings per year (ISSER, 2017). The management of the poultry droppings is poor in the farms as these are dumped indiscriminately on land and sometimes burnt. This improper management create a lot of environmental problems due to emissions of greenhouse gases, volatilization of ammonia (NH_3) and nutrient leaching (Liu *et al*., 2020).

The poultry litter is rich in plant essential nutrients, particularly, nitrogen, phosphorous and potassium and micronutrients as well (Agyarko-mintah *et al*., 2016). Poultry litter is known to improve soil pH when applied in adequate quantities (Nuhu *et al*., 2012).

2.2 Declining of soil fertility in Africa

In most African countries including Ghana, the economy depends mostly on agriculture. The intensive increase in population put pressure on land due to inappropriate practices which cause the reduction of fallow periods, fertility regeneration limitation and increase in cultivation of marginal soils which result in soil degradation (Drechsel, Gyiele, Kunze, & Cofie, 2001). African countries are facing continuous imbalance between nutrient inputs (manure, fertilizers, atmospheric deposition, biological nitrogen fixation and sedimentation) and nutrient outputs (removal of crop residues, products harvested, leaching, gases emissions, erosion and surface runoff) (Stoorvogel &Smaling, 1990). In harvesting, crop farms loose plenty of nutrients by means of crop residues. These nutrients cannot be replenished by fertilizer application, which leads to soil nutrients mining (Munongo, Nkeng, & Njukeng, 2017). Therefore, there is a need of recycling the agricultural wastes to soil for its sustenance.

2.3 Potential of organic residues as soil amendments

The application of agricultural wastes on land is considered as the primary waste utilization procedure, and nitrogen, phosphorous and potassium are the essential nutrients to consider in the management plan of agricultural (Partey, Preziosi, & Robson, 2014).

In general, the use of organic manures and compost enhances soil organic carbon (SOC) more than the application of the same amount of nutrients in the form of inorganic fertilizers (Gregorich, Drury, & Baldock, 2001). There are a lot of studies that demonstrated that application of compost from crop residues affected positively the soil physical, chemical as well as biological properties which enhance the growth and development of crops thereby increasing the yield. For example; the yield of field-grown cabbage and onion was reported for the soil fertilized with 25% compost. Similarly, comparison of the yield of amaranth grown on the soil fertilized by crop residue compost and without compost found a yield increase of 46% for the compost use (Akanbi & Togun, 2002). A rapid decomposition of poultry manure in the soil and release of more available N and P as compared to cow dung and biogas-slurry was reported (Sheikh *et al*., 2015).

2.3.1 Biochar and its role in the sustainability of agriculture and environment

Biochar is a solid product rich in carbon, obtained by thermochemical conversion of biomass residues from a wide range of organic feedstock without or with minimum oxygen. Biochar can be acidic or basic, hydrophilic or hydrophobic (Glaser & Lehr, 2019). It is a form of organic carbon with high persistence in the soil and act as soil carbon sink (Söderqvist, 2019). The challenge of combatting accelerating global warming and anthropogenic land degradation, has created a strong interest in biochar research since the last decade (Schmidt, Pandit, Cornelissen, & Kammann, 2017). Currently, the production of biochar by pyrolysis is proved as an alternative strategy for the management of organic wastes. Apart from being rich in plant nutrients and carbon sequestration,

Biochar production reduces waste volume and eliminates other harmful residues such as antibiotics (Xiao *et al*., 2018).

The kind of feedstock and process conditions (mostly temperature and time) influence its interaction with the environment and its fate (Sohi *et al*., 2009). Biochar have been reported to improve soil properties such as to increase soil pH (Bahrun *et al*., 2018), water holding capacity and soil aeration (Duarte & Glaser, 2019), cation exchange capacity, total organic carbon and other plant nutrients contents as well, thereby improving the status of soil nutrient and affecting microbial community structure (Gao *et al*., 2017; Abujabhah *et al*., 2016; Ducey, Novak, & Johnson, 2015).

The high porous structure, improved water retention potential, increased soil surface area and increased nutrient use efficiency make the biochar attractive as soil amendment thereby resulting in high crop yields which is expected to mitigate pressures on land and would have pertinence to land restoration and remediation (Sohi *et al*., 2009).

Biochar act as both carbon sink and provide long-lived soil benefits due to its chemical and biological stability characteristics (Prakongkep *et al*., 2013). Long-term carbon sequestration of biochar is attributed to its aromaticity, amorphous structure and higher cation exchange capacity reduce the accessibility to decomposers (Warnock et al., 2010). Biochar promotes storage and stability of soil carbon due to its potential of increasing organic and total carbon (Ali *et al*., 2019).

Biochar has been reported to lower carbon dioxide emission when used in co-composting of manures (Yemisi *et al*., 2019).

2.4 Contribution of agriculture on air pollution and climate change

Human activities including agriculture have been substantially increasing the concentration of atmospheric greenhouse gases (ex: CO_2 by 31% between 1750 and 2000, and by 80% between 1970 and 2004) which enhance the Greenhouse effect resulting in additional warming of Earth's surface and atmosphere. This change in Earth's climate have adverse impacts on natural ecosystem; there are expectation of severe human health impacts such as increased summer deaths, increased risk of drowning, diseases and hunger due to flooding.

There is a Significant amount of CO_2, N_2O and CH_4 released from agriculture (Paustian, 1997; IPCC, 2001; Paustin *et al*., 2004). Agriculture contributes about 13.5% of global GHG emissions and are likely to increase (FAO, 2011; Lal *et al*., 2019).

2.5 Decomposition and Mineralization

Decomposition is "the biological breakdown and biochemical transformation of complex organic molecules of dead materials into simpler organic and inorganic molecules" (Palm, Giller, Mafongoya, & Swift, 2000). The physical fragmentation of the organic residues into smaller particles is due to soil organisms of various size; macro, meso and micro fauna. This fragmentation increases the surface area which facilitates the microbial colonization and subsequent hydrolysis by microbial enzymes which degrade complex polymers into monomers and ions, which can be absorbed by the plants or microbial cells (Valadares, Silva, & Teixeira, 2016). Mineralization is defined as ''the biological process of converting organic molecules to inorganic compounds''.

(Grzyb *et al*., 2020). The nutrients released from crop residues by means of decomposition and mineralization are accessible for microbial uptake and plants (Mohan, 2017).

2.5.1 Factors affecting organic residues decomposition and mineralization

The decomposition and mineralization of organic residue is influenced by a number of factors of which the identified are the residue quality (Datta *et al*., 2019), environmental factors (Zhu *et al*., 2020), microbial community structure and composition and soil conditions (Audel, Ossa, & Arleen, 2015), nutrient availability and priming effect of root exudation and rhizosphere (Singh, Rengel, & Bowden).

2.5.1.1 Organic residue quality

The difference in physicochemical properties of organic residues explains differences in decomposition dynamics (Cavalli, Corti, Baronchelli, Bechini, & Gallina, 2017). The quality of the crop residues influences the degradation process, as it generally reduces throughout the decomposition due to the loss of readily accessible carbon and the accumulation of recalcitrant compounds (Liu *et al*., 2020).

2.5.1.1.1 Chemical properties

The decomposition rates and the dynamics of nutrients are determined by residue characteristics such as Carbon/nitrogen ratio, carbon/phosphorous ratio, lignin/nitrogen ratio as well as cellulose, hemicellulose, lignin, polyphenols, proteins, sugars and waxes contents (Yue *et al*., 2016).

The decomposition rate is enhanced by low C: N ratio (Lazicki, Geisseler, & Lloyd, 2020), low lignin/N, high concentration of total phenolic and low polyphenol concentration as well as high concentration of non-structural carbon (Audel *et al*., 2015). Du *et al*. (2020) reported a significant correlation between mass loss and sixteen leaf litter chemical properties (C, N, P, K, Ca, Mg, lignin and cellulose) except some N/P ratios; there was also a significant correlation between nutrient release and leaf chemical properties (Du *et al*., 2020).

The C: N ratio plays an important role in decomposition rates and mineralization. Generally, it is assumed that the C: N ratio greater than 25:1 cause the inorganic nitrogen to immobilize because of insufficient nitrogen for microorganism's satisfaction (Grzyb *et al*., 2020). It is reported that the decomposition is faster with the material with C: N ratio below 20 and slower with the material with C: N ratio above 20 (Swift, 1981). Low carbon content leads to high rate of decomposition whereas for nitrogen, the lower the nitrogen content in the residue, the lower the decomposition rates (Uzoh *et al*., 2015). Low C: N ratio showed to enhance rapid mineralization in the soil up to 45 days of organic C and N from animal production waste (Diana, Araújo, Feitosa, & Primo, 2020). The residue with high total P and N contents were found to decompose faster (Iqbal, 2009).

It is suggested that high polyphenol concentration in organic residues may enhance the availability of nitrogen by organic N sequestration in the form of Protein-Polyphenol complex in infertile soils (Majuakim & Kitayama, 2013). Polyphenol content has been reported to control nitrogen mineralization of crop residues especially the leguminous residues (Iqbal, 2009).

Lignin is an aromatic compound which is complex and hard to be decomposed due to the structure complexity, insolubility as well as high molecular weight (Vanderbilt, White, Hopkins, & Craig, 2020). Lignin is mainly decomposing by basidiomycetes and ascomycetes species (Pérez *et al*., 2002). Cellulose; a constituent of the residue organic matter is important in nitrogen mineralization due to its ability to rapidly break down. Cattanio *et al*. (2008) suggested that cellulose, as a C source, and polyphenol content may control the short-term N and P release and availability from mulch.

2.5.1.1.2 Physical properties

Physical quality or surface properties like the thickness of cuticle, structures such as spine, toughness and particle size influence microbial colonization and hence affect the decomposition and mineralization patterns (Bending & Turner, 1996). Particle size influences the available surface area for soil micro-biota colonization and will have an influence to water exchange, nutrients and oxygen between the soil matrix and the substrate. Particle size also influences the contact of the material with silt and clay particles, which may protect organic materials from microbial attack (Hassink, 1997; Bending & Turner, 1999).

The soil microbial population are influenced by particle size of the crop residue material incorporated into soil, however, the effect depends on the plant material biochemical quality as well as stage of decomposition. Bending and Turner (1999) found no influence of particle size on N mineralization for the highest biochemical quality crop residues while for low biochemical quality residues; reducing particle size affected early microbial respiration and net mineralization of nitrogen. Walpola & Arunakumara (2009) reported that fine particles also found to have a greater mineralization than coarse particles, this is contrary to the findings of Jensen (1994) who reported a greater decomposition and mineralization in coarse particles than fine particles and he indicated that it could be due to high protection of clay minerals to the microbial biomass and metabolites during initial decomposition. A Fifty- days laboratory study on barley residues particle size also showed that the rate of C mineralization of the residues was higher in chopped than sieved residues (Loomis, Rogers, & Sihi, 2020).

2.5.1.1.3 Other factors including method of application and quantity

Applying crop residues on soil surface offset soil moisture deficit as well as enhancing N mineralization (Ibrahim, Khan, Ali, & Akbar, 2020). Increased N mineralization in surface applied organic residues as compared to soil incorporated residues has been reported (Lal *et al*., 2019; Datta *et al*., 2019). A study carried out by (Loomis *et al*. (2020) showed that the rate of C mineralization of the residues was high in surface applied residues and low in incorporated counterpart. On the other hand, Abiven and Recous (2007) studied the effect of crop residues incorporation or surface application on decomposition and mineralization and found no difference in C mineralization but with a higher N mineralization for the surface applied as compared to incorporated residues for brachiaria and soybean residues, while for rice, wheat and sorghum, different results were observed (Abiven & Recous, 2007).

The rate of decomposition is proportional to the initial amount of amendment added (Six, Conant, Paul, & Paustian, 2002). It is revealed that soil amended with higher rate of crop residue increased carbon mineralization potential, indicating labile soil organic matter (Ghimire *et al*., 2017). It has been reported that high manure loading rated influenced the nitrification and the microbial community function and activity in lighter soils (Abujabhah *et al*., 2016). Shakoor *et al*. (2020) also reported that manure application rates increases C, N, P and K mineralization.

2.5.1.2 Environmental factors

During decomposition, activities of microorganisms are controlled by environmental factors such as humidity, oxygenation, temperature and rainfall. In temperate climates, the decomposition and mineralization rates of crop residues is usually slower than in tropical climates and when the mean air temperature increase by 8-9°C, the rate doubles (Pangnakorn *et al*.,2013). Hu *et al*. (2014)

studied the effect of six temperature ranges i.e. -10, 5, 15, 25, 35 and 40°C and four rainfalls amounts; 5,10,15 and 30mm on the mineralization rates of crop residues and found that higher temperatures i.e. 25, 35 and 40°C and moderate rainfalls quickened mineralization of nitrogen in the soil. Analysis of the decomposition and mineralization of soybean residues showed that nitrogen releases faster with increasing humidity (Hood, 2001).

2.5.1.3 Physico-biochemical properties of the soil

Physical and biochemical properties of the soil such as soil mineralogy, soil texture and compaction, acidity, soil aeration, soil nutrients as well as biological factors like antagonistic of predatory organisms play an important role in determining the decomposition and mineralization rates (Walpola, 2010). These factors influence microbial activity in the soil which affects the mineralization activity (Dey *et al*., 2019).

The texture of the soil stimulates porosity, surface area, permeability and the dynamics of water and nutrients (Mohan, 2017) which facilitate microbial activity (Audel *et al*., 2015). Soils with higher clay proportion and high exchange capacity are reported to slow down the decomposition rates of organic amendments (Jensen, 1994; Grant *et al*, 1993).

Low pH may limit the biochemical decomposition especially in flooded areas (Chen *et a*l., 2015; Giweta, 2020). Organic matter and soil nutrients especially nitrogen and phosphorus affect decomposition by controlling the soil organism's population and activities (Giweta, 2020). The soil with high organic carbon modifies the C: N ratio, encouraging bacteria activity with greater nitrogen degradation and loss of ammonia (Verdi *et al*.,2018).

Soil moisture and temperature influence nitrogen availability from organic materials depending on the type of the material (Agehara & Warncke, 2005; Kvitkina, 2017). Seyferth (1998) studied the effect of soil temperature and moisture on mineralization and found that the mineralization rate to be high at 25°C and 60% water holding capacity. Water-saturated soils are shown to assist the diffusion of oxygen into the soil which affects respiration of microorganisms resulting in lower organic matter decomposition (Mohammed, Naab, Nartey, & Adiku, 2014).

Large quantities of agricultural wastes are generated in Ghana and they can be used in various forms (direct application, composting and charring) to increase the productivity of the soil. This amount of agricultural wastes can reduce the amount of money spent on mineral fertilizers if most of it is used in crop production.

2.6 Reasons of monitoring carbon dioxide emissions

2.6.1 Carbon dioxide emission from soil and its adverse impacts

Deposition or incorporation of organic residues in the soil undergo biological degradation in which carbon is used in by decomposers in respiration, which releases carbon dioxide (Chen *et al*., 2015). Carbon dioxide is greenhouse gas which contribute to the Greenhouse effect resulting in additional warming of Earth's surface and atmosphere, increase of the global average surface temperature. This change in Earth's climate have adverse impacts on natural ecosystem and humankind; there is expectation of severe human health impacts including increased summer deaths, increased risk of drowning, diseases such as malaria, dengue and hunger from flooding due to climate change which is caused by carbon dioxide emissions (Schomberg, 2012).

2.6.2 Factors that affect carbon dioxide emission

Carbon dioxide, as well as other greenhouse gas emissions from agriculture depends on the amount and type of added materials, characteristics of the soil/soil processes, environmental conditions, particularly temperature and water availability (Hossain *et al*., 2017; Agehara & Warncke, 2005). The meta-analysis carried out by Shakoor *et al*. (2020) showed that poultry manure emits higher amount of carbon dioxide from the soil than cattle and pig manures.

2.7 Reasons of monitoring ammonia volatilization

2.7.1 Ammonia emissions from soil and its adverse impacts

Ammonia is one of the main form of nitrogen emitted during different processes including decomposition of manures and other organic residues. Apart from environmental problems posed by ammonia, ammonia volatilization is also one-way of nitrogen loss from the soil thereby causing economic loss. Ammonia is a precursor of secondary respirable and fine particles (particulate matter) (Batton-hubert, 2012). Ammonia deposition especially as particulate matter leads to acidification and eutrophication in the environment. In aquatic environments, ammonia deposition can lead to excess nutrients which cause the reduction in oxygen quantity (Hassouna *et al*., 2017).

2.7.2 Factors that affect ammonia emission

Ammonia emissions is influenced to the composition of manure, soil conditions, and environmental conditions at the time of application. The concentration of total ammoniacal N and manure dry matter, soil infiltration rate, and climatic variables such as air temperature, irradiation, wind speed, and rainfall are the most prevalent elements reported to affect ammonia losses (Sommer & Hutchings, 2001). It is reported that the presence of high organic carbon content causes the modification of C: N ratio and motivates the bacteria activity with greater N degradation and ammonia losses (Verdi *et al*., 2018).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

A study was conducted to assess the management practices of major agricultural wastes and evaluate the impact of some of these wastes on decomposition and mineralization, as well as carbon dioxide (CO_2) and ammonia (NH_3) emissions.

3. 1. 1 Geographical location

This study was undertaken within the Kwaebibirem District in the Eastern region of Ghana (Fig.3.1). The Kwaebibirem District is one of the 27 districts that constitute Eastern region of Ghana. The capital of the district is Kade. The district has a population of about 113,721 in which 57.3% reside in rural areas while the remaining 42.7% reside in urban areas.

3. 1. 2 Relief and drainage

Generally, the relief is less than five hundred (500) meters above sea level with a major mountain range, located in the North-West of the district called Atiwa. There are extensive marshy lands in between heights. From the North to the South, there is the Birim river which flows through the district. Kadepon, Subinsa, Apaam and Pram rivers are also noticeable.

3. 1. 3 Climate

The Kwaebibirem district lies in the tropical zone and experiences double maxima rainfall regimes with two distinct dry and wet seasons. Temperature ranges between 25ºC- 30ºC. Usually, the average temperature is between 26.5-27 ºC.

3. 1. 4 Vegetation

The Kwaebibirem district is characterized by a Semi-Deciduous vegetation consisting of three layer plants with a densely undergrowth. Though anthropogenic activities such as lumbering and fuel wood extraction and mining among others have substantially reduced the original vegetation, the district is characterized by different species of herbs, scrubs, weeds and trees.

3. 1. 5 Geological resources

The district is characterized by three major soils associations that have been developed over the lower Birimean soil type. The three soils are: Birimean-Chiciwere, Bekwai-Oda and Atiwa-Asikuma-Asum. In these soil associations; Diamond, Gold, Bauxite and other minerals are endowed. The district is a favorable for cultivating cash and food crops.

3. 1. 6 Economic activities

Agriculture is the main activity practiced by the majority of the population in the district; both commercial and subsistence production of cash and food crops. Manufacturing industries mainly small and medium and service sector are also noticed.

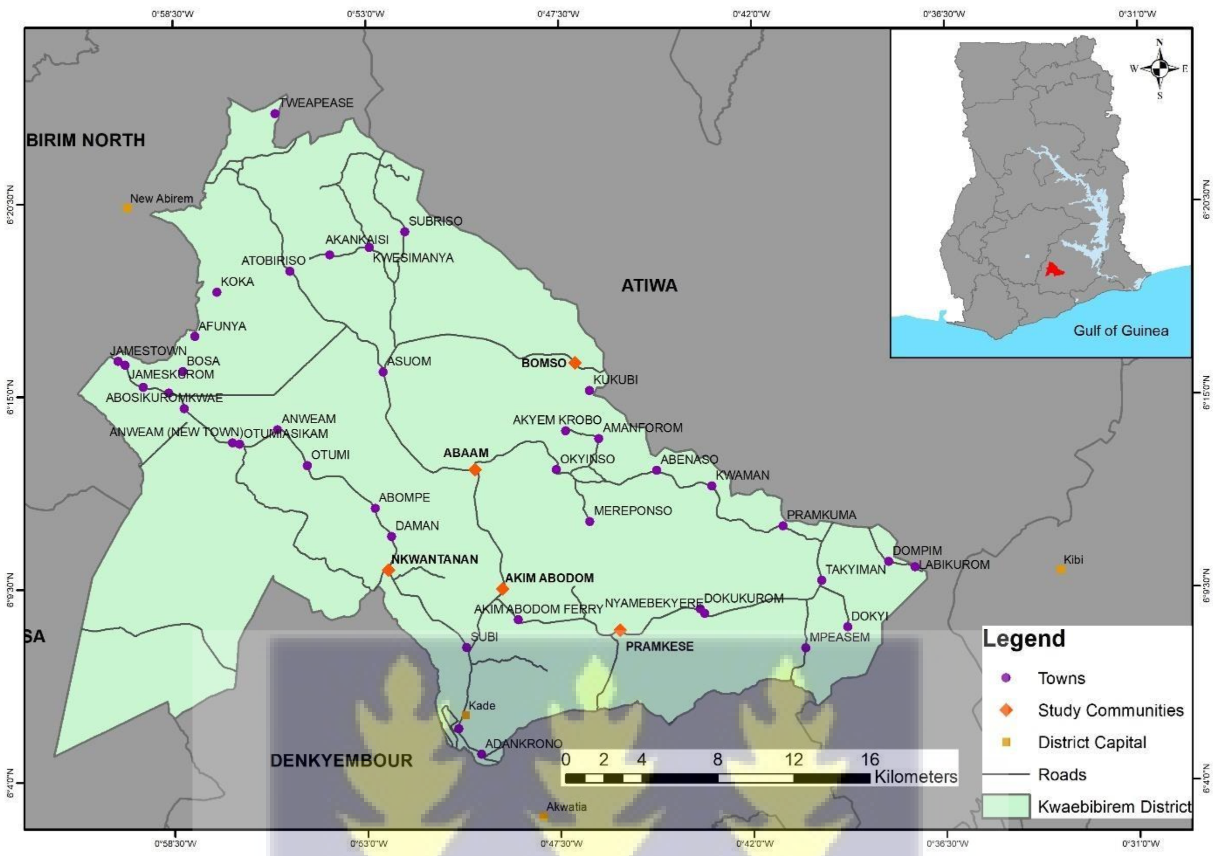

Figure 3. 1 Map of Kwaebibirem District showing the study communities

3. 1. 7 Determination of sample size for the study

In order to get a representation of the farmers within the study area, Yamane's formula was used to determine the sample size of the respondents as illustrated below. Thus 95% confidence level and 5% level of precision was used (Glenn, 2003).

$$n = \frac{N}{1 + N(e)^2}$$

Where n= sample size; N= population size and e= marginal error (5%)

3. 2 Experimental site

The decomposition and mineralization experiment was conducted at the Livestock and Poultry Research Center (LIPREC), University of Ghana; The gases (CO_2 and NH_3) emissions experiments and other analysis were conducted at Biotechnology and Nuclear Agriculture Research Institute (BNARI) at Soil and Environmental Sciences Research Centre (SESRC) at Ghana Atomic Energy Commission, Accra.

3. 3 Study Design

The mixed research approach was adopted for this study. Data were collected from primary and secondary sources. Descriptive Study method; A social survey was conducted using questionnaires to farmers from five communities of Kwaebibirem District. Primary data were obtained directly from farmers in five communities namely; Nkwantanan, Pramkese, Abaam, Abodom and Bomso. Questionnaires, direct personnel observations and in-person interviews were used in collecting the survey data. The data from laboratory experiments and analysis were also gathered.

3.4 Sampling and preparation of soil and agricultural wastes used in the study

The soil used in this study was collected from University of Ghana, Forest and Horticultural Crop Research Centre, Kade. Soil samples (150kg) were collected using auger (0-30cm depth). The soil samples were air dried and sieved to 2mm sieve prior to physicochemical analysis and use in experiments. The organic wastes used in this study are; empty fruit bunches from palm oil industry, cocoa pod husks, poultry droppings and rice husk biochar.

Empty fruit bunches and cocoa pod husks were collected from University of Ghana, Forest and Horticultural Crop Research Centre, Kade in the Kwaebibirem district. Cocoa pod husks and EFB were air dried about 2 weeks. Cocoa pod husks were crushed using a hammer, EFB were cut into different sizes. The crushed cocoa pod husks (CPH) and Empty Fruit Bunches (EFB) were passed through sieves (26mm and 13mm) to obtain three different particle sizes which are: (<13mm), (13-26mm) and (>26mm). Poultry droppings were collected from Kingdom farm, Kwaebibirem District; rice husk biochar was also collected from Kwaebibirem District and acidified using 1M HCl to achieve different pH (Doydora *et al*., 2011). A 2, 1.6 and 1ml of 1M HCl was added to 10g of rice husks biochar to obtain biochar with pH8, pH6 and pH4, respectively. Sub-samples of air dried organic residues were oven dried at 60°C until constant weight. The oven dried samples were grounded and passed through a 0.2mm sieve and stored at 4°C for physical and biochemical analysis (Total Organic carbon, Total Nitrogen, Total Phosphorous, Total Potassium, Calcium, Magnesium, lignin and polyphenols concentrations, C/N, C/P and Lignin/N).

3.5 Experimental Design

Incubation studies were conducted at the laboratory under ambient conditions in a Completely Randomized Design (CRD) with three replications. Litterbag method (Karberg *et al*., 2008) was used for the experiments. The experiments were carried out using Polyvinyl chloride (PVC) containers (17cm diameter and 12.3cm in depth). Each PVC was filled with 1kg of air-dried and sieved soil (dry weight basis), moistened and pre-incubated for 2 days in the incubation room at room temperature, 28°C to initiate microbial activities (Molindo, 2008). A 50g sample of organic residues in a nylon mesh bag (2mm mesh size) was placed on the surface of the soil in the PVC to avoid the organic residue loss by wind or other factors. Fifty (50) ml of distilled was added to each treatment every three days in order to maintain the moisture at 60% throughout the experimental period. Destructive sampling (permanent removal of experimental unit from incubation room for laboratory analysis) was done for decomposition and mineralization experiments.

3.5.1 Experiment I: Assessing the effect of organic residues type and particle size on CO_2 emission

Carbon dioxide emission experiment was carried out using the PVC and nylon mesh bags as previously described in Experimental design section. As shown in table 3.1, EFB and CPH are the two types of organic residues used and for each residue, three particles sizes were considered. The experiment was carried out from April to August, 2021.

Table 3. 1 Detailed description of treatments used in assessing the effect of organic residues type and particle size on CO_2 emission

Treatments	Treatment name	Description
T1	EFBS1	EFBS1: (>26mm)
T2	EFBS2	EFBS2 : (13mm-26mm)
T3	EFBS3	EFBS3 : (<13mm)
T4	CPHS1	CPHS1: (>26mm)
T5	CPHS2	CPHS2 :(13mm-26mm)
T6	CPHS3	CPHS3 : (<13mm)
T7	Soil	Soil only
T8	Blank	Blank

Figure 3. 2 Layout of laboratory experiment showing chambers for trapping emitted carbon dioxide

The method used was adopted from Stotzky (1965). Each of the treatments in a nylon mesh bag was placed on the surface of the soil in the PVC. A 20ml portion of 2M NaOH solution in the beaker was placed along the PVC to trap the carbon dioxide evolved and covered tightly with a plastic container. At each sampling dates, a new 2M NaOH solution replaced the collected/removed solution for CO_2 evolution determination. The removed content/carbonate formed was precipitated using 22ml of 1.5M $BaCl_2$, and the excess NaOH was back titrated against hydrochloric acid (2N HCl) using phenolphthalein indicator (Stotzky, 1965). Sampling was conducted in two days' interval in the first two weeks and four days' interval in the next four weeks and once a week until the end of incubation period of 120 days. The CO_2 evolved from each treatment was calculated as follows:

CO_2 (mg) evolved per time (t) = $\frac{(B-V)NE}{\text{Weight of the sample}}$

where B= volume (ml) of acid needed to titrate the NaOH in the blank container to the end point.

V= volume (ml) of acid that was needed to titrate the NaOH in the container exposed to the organic residue

N= Normality of the acid used

E= Equivalent weight (in terms of CO_2, E = 22)

The amount of CO_2 evolved from organic residue was obtained by subtracting the amount obtained from treatment (residue + soil) from the amount obtained from the control (soil only).

3.5.2 Experiment II: Assessing the effect of organic residue type and particle sizes on decomposition and nutrient release patterns

This experiment was conducted from March to August, 2021 to assess the effect of organic residue type (EFB and CPH) and particle size on mass loss and nutrient release patterns. A total of 90 experimental units were incubated (6 treatments × 5 sampling dates × 3 replicates). Destructive sampling was done after 2, 4, 8, 12 and 22 weeks of incubation.

Table 3. 2 Detailed description of treatments used in assessing the effect of organic residue type and particle size on decomposition and nutrient release patterns

Treatments	Treatment name	Description
T1	EFBS1	EFBS1: (>26mm)
T2	EFBS2	EFBS2 : (13mm-26mm)
T3	EFBS3	EFBS3 : (<13mm)
T4	CPHS1	CPHS1: (>26mm)
T5	CPHS2	CPHS2 :(13mm-26mm)
T6	CPHS3	CPHS3 : (<13mm)

Figure 3. 3 Layout of decomposition and nutrient release experiment showing experimental units

3.5.2.1 Sampling during incubation period

At each sampling time, samples were collected and adhered soil was removed gently and put into labelled envelops and dried at 60ºC until constant weight (Du *et al*., 2020). The dry weight was recorded. The residues were ground and sieved through 0.2mm sieve and kept at 4ºC for further analyses.

3.5.2.2 Determination of mass loss of organic residues

The mass loss of organic residues was estimated using the formula of Breitenbeck & Schellinger (2004).

$$L\ (\%) = \frac{W_t}{W_0} \times 100$$

Where L is the % remaining organic resource dry weight after a sampling period in weeks; W_0 is the initial organic resource dry weight; W_t. is organic resource dry weight of the remaining organic resources in the nylon mesh bag at time (t)

Decomposition rate constant (k) was determined following the single exponential model of Olson (1963) as follows:

$$\mathbf{W_t = W_0 e^{-kt}}$$

Where:

W_t = remaining dry weight after time (t)

W_0 = initial dry weight

k = decomposition rate constant

t = time (weeks)

3.5.2.3 Determination of Nutrient release from organic residues

The nutrient release from organic residues was estimated using the formula of Moradi *et al*. (2014) as follows:

$$\mathbf{R\ (\%)= \frac{W_t\, C_t}{W_0\, C_0} \times 100}$$

Where R is the percent remaining nutrient; W_0 is the initial organic resource dry weight; W_t. is organic resource dry weight of the remaining organic resources in the litter bag, C_0 is % of the nutrient in the initial organic resource; C_t is % of the nutrient in the remaining organic resource at time (t).

3.5.3 Experiment III: Assessing the effect of biochar amendment to poultry droppings on CO_2 emission

This experiment was conducted in January, 2021 to assess the effect of rice husk biochar (at different pH and application rates) amendment to poultry droppings on CO_2 evolution. The experiment was carried out using the PVC and nylon mesh bags as previously described in Experimental design section. The treatments used are shown in the following table.

Table 3. 3 Detailed description of treatments used to assess the effect of biochar amendment to poultry droppings on CO_2 emission

Treatments	Description	Detailed description
T1	PD + RHB (pH4, 5%)	Application of RHB @ 5% at pH4
T2	PD + RHB (pH4, 10%)	Application of RHB @ 10% at pH4
T3	PD + RHB (pH6, 5%)	Application of RHB @ 5% at pH6
T4	PD + RHB (pH6, 10%)	Application of RHB @ 10% at pH6
T5	PD + RHB (pH8, 5%)	Application of RHB @ 5% at pH8
T6	PD + RHB (pH8, 10%)	Application of RHB @ 10% at pH8
T7	100 % PD	No RHB application
T8	Soil	Soil
T9	Blank	Blank

Carbon dioxide emission from poultry droppings as affected by biochar application at different pH and rates was assessed according to Stotzky (1965). The same procedures as described in experiment I were followed. Sampling was conducted every day in the first week, every two days in the second week, every three days in the second and third week and four days' interval until the end of incubation period of 30 days.

3.5.4 Experiment IV: Assessing the effect of biochar amendment to poultry droppings on NH_3 emission

This laboratory experiment was conducted using the PVC and nylon mesh bags as previously described in Experimental design section to assess the effect of rice husk biochar (at different pH and rates) amendment to poultry droppings on NH_3 evolution. The treatments used are shown in the following table.

Table 3. 4 Detailed description of treatments used in assessing the effect of biochar amendment to poultry droppings on NH_3 emission

Treatments	Description	Detailed description
T1	PD + RHB (pH4, 5%)	Application of RHB @ 5% at pH4
T2	PD + RHB (pH4, 10%)	Application of RHB @ 10% at pH4
T3	PD + RHB (pH6, 5%)	Application of RHB @ 5% at pH6
T4	PD + RHB (pH6, 10%)	Application of RHB @ 10% at pH6
T5	PD + RHB (pH8, 5%)	Application of RHB @ 5% at pH8
T6	PD + RHB (pH8, 10%)	Application of RHB @ 10% at pH8
T7	100 % PD	No RHB application

Each treatment sample was enclosed in incubation plastic container together with a beaker containing 20ml of 4% boric acid to trap ammonia evolved. On each sampling date, a fresh boric acid solution of the same volume and concentration replaced the collected/removed solution. The removed content (boric acid solution that trapped ammonia) was titrated against hydrochloric acid (0.025N HCl) using Tashiro's indicator (Martín, Sarria, & Asuero, 2017). Sampling was conducted every day for the first week, every two days in the second week and five days' interval until the end of incubation period (30 days). The ammonia evolved was calculated as follows (Liu *et al.*, 2017).

$$\textbf{Ammonia evolved (ppm)} = \frac{V \times N \times 17 \times 1000}{W}$$

Where 17 is the molar mass of ammonia,

N and V are the normality and the volume of the titre (HCl) respectively,

W is the weight of the sample

Figure 3. 4 Layout of laboratory experiment showing chambers for trapping emitted ammonia

3.5.5 Experiment V: Assessing the effect of biochar amendment to poultry droppings on nutrient release

Twenty-one experimental units (7 treatments × 3 replications) were incubated. Sampling was done after one month after incubation. Sampling and determination of nutrient release in the residues was done following the same procedures as described in experiment II. The following table shows the treatments used for this experiment.

Table 3. 5 Detailed description of treatments used in assessing the effect of biochar amendment to poultry droppings on nutrient release

Treatments	Description	Detailed description
T1	PD + RHB (pH4, 5%)	Application of RHB @ 5% at pH4
T2	PD + RHB (pH4, 10%)	Application of RHB @ 10% at pH4
T3	PD + RHB (pH6, 5%)	Application of RHB @ 5% at pH6
T4	PD + RHB (pH6, 10%)	Application of RHB @ 10% at pH6
T5	PD + RHB (pH8, 5%)	Application of RHB @ 5% at pH8
T6	PD + RHB (pH8, 10%)	Application of RHB @ 10% at pH8
T7	100 % PD	No RHB application

3.6 Physico-chemical analysis of soil and organic residues used in the study

The Physico-chemical assessment of organic residues and soil used in this study was carried out. Soil samples were analyzed of soil texture, pH, bulky density, moisture content, EC, CEC, TOC, N, P, K, Ca^{2+} and Mg^{2+} contents. Organic residues were analyzed for pH, DM, OM, TOC, N, P, K, Ca^{2+} and Mg^{2+}, lignin, cellulose and phenolic acid contents.

3.6.1 Determination of Soil Texture

Soil texture was determined by the Hydrometer method. Soil was dispersed by adding 30% of hydrogen peroxide and heat to destroy organic matter. A 40g of sieved soil was put into a beaker and 100ml of 5% sodium hexametaphosphate solution was added. The suspension was shaken on a mechanical shaker for 2 hours followed by transferring to 1L sedimentation cylinder and water was added until it reached to 1L mark. Using a plunger, the content was mixed vigorously about 30 seconds. The suspension was allowed to settle and gently the hydrometer was lowered into the suspension; the hydrometer readings at 40 seconds represent silt and clay, the readings after 8 hours represent the clay. The sand fraction was obtained by decanting the suspension from the sedimentation cylinder and recording the dry weight after it had been oven-dried at 105°C for two days and cooled in a desiccator. USDA textural triangle was used to determine soil texture.

3.6.2 Determination of pH

Ten grams of each air-dried sample was weighed into 50ml beaker and 25 ml of distilled water was added (1: 2.5 soil: water). The mixture was stirred vigorously several times for about 10 and allowed to stand for 30 minutes to allow settlement of suspended clay. The standardized pH meter, Hanna Instrument (HI) Combo 99301(calibrated with standards at pH 4.01 and 7.00) was used. The electrode was inserted into the supernatant of suspension and the pH of the sample was read with pH meter (Makinde & Ayeni, 2013).

3.6.3 Determination of Moisture Content

Ten grams of air-dried sample was kept in an oven at 105°C for 24 hours and the weight was recorded after drying. The moisture content was calculated using the following formula (Ibrahim et al., 2020);

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Dry weight}} \times 100$$

3.6.4 Determination of Electrical Conductivity

Ten grams (10g) of air- dried sample was weighed into 25ml distilled water in a beaker and shaken for 1 hour. The suspension was allowed to stand for about 10 minutes. Conductivity electrode of calibrated EC meter (Hanna Instrument Combo 99301) was deep into supernatant to read the EC.

3.6.5 Determination of Cation Exchange Capacity

Five grams of the sample was weighed into an extraction bottle and 50ml of ammonium acetate was added. The mixture was then shaken for 30 minutes and filtered through Whatman filter paper No.42. The non-adsorbed ammonium was washed off with methanol and the ammonium saturated soil was leached four times with acidified 1M KCl. The ammonium ion concentration (mol/L) in the KCl filtrate was then read on an ELIT 9808 ion analyzer and the CEC of the soil in cmol/kg was estimated.

3.6.6 Determination of Bulk Density

A 2cm surface soil was removed from the level area where samples were to be measured. A 5cm diameter thin-sheet metal tube of known weight (W1) and volume (V) was inserted into the soil surface and excavated the soil from the tube and cut the soil beneath the bottom of the tube and excess soil was removed from the tube ends with a knife. The soil was dried at 105°C for two days and weighed (W2) and bulk density was calculated as follows:

$$\text{Bulk density (g/cm}^3\text{)} = \frac{W2 - W1}{V}$$

3.6.7 Determination of Organic Carbon and Nitrogen

Organic carbon and nitrogen of the samples were determined using TruMac CNS analyser, (model: LECO TruMac CNS analyser). About 0.25g of each sample was weighed into a ceramic boat and then loaded into a purge chamber. The entrained atmospheric gas was purged from the sample and the ceramic boat was inserted into the furnace regulated at a temperature of 1350ºC. Complete oxidation of the sample was done by highly purified oxygen gas. At the end of the combustion, the ceramic boat and all ash from the sample were removed from the furnace. Removed from the furnace by chemical anhydrone. The remaining combustion gases were collected and equilibrated in a ballast where an aliquot was taken for carbon, nitrogen and sulfur determination. The sample aliquot gases were passed through an infrared detector for carbon and sulfur and then onto a heated copper reagent to remove oxygen and convert NO_2 to N_2 gas and then passing through Lecosorb and anhydrone to remove carbon dioxide, sulfur gases and water by-products. The remaining nitrogen gas was passed through thermal conductivity detector to determine nitrogen. An external Computer with windows operating software did all the quantitative calculations and the results were displayed as weight percentage.

Organic matter was calculated from organic carbon using the following formula:

$$OM\ (\%) = OC\ (\%) \times 1.742$$

3.6.8 Determination of total Phosphorous

A 1.0 g of dried sample was measured and placed in a clean and dried digestion tube. Tablets of selenium catalyst and 20ml of sulphuric acid was added. The mixture was heated until the solution turned clear. The flask was removed from the heater and cooled. The mixture was transferred into a 100ml volumetric flask and 50ml of distilled water was added. The solution was filtered through Whatman No.42 filter paper. The working solution was prepared by mixing 20ml of Acid Mollybdate solution (reagent A) and 10ml of Ascorbic acid solution (reagent B). 800ml of distilled water was added and allowed to dissolve and later topped up to 1L with distilled water.

The standards P solutions were prepared as follows: 1000ppm of stock solution was prepared by weighing 1.0982g of dried monopotassium phosphate (KH_2PO_4) into 250ml of distilled water. 10ppm solution was made from 1000ppm solution by diluting 10ml from stock solution to 1L with distilled water. 0, 1, 2, 3, 4, 5, and 6 mL of the standard P solution above were pipetted into 50 mL volumetric flasks. 5ml of the digest solution was measured into 50ml volumetric flasks. For both standards and samples; 30ml of distilled water was added followed by drops of P-nitro phenol and enough Ammonium solution until the sample solution turns yellow. 10ml of ascorbic acid working solution was added and waited for one hour to allow the blue color development. The standards and samples absorbance at 880nm wavelength was measured using UV-1600PCUV/Vis Spectrophotometer. The standard curve of absorbance versus concentration was plotted in excel graph and the concentrations of the sample solutions was determined. Phosphorous concentration in percent was calculated as follows:

$$\text{P (\%)} = \frac{\text{meter reading} \times \text{digest volume} \times 100}{\text{sample weight} \times \text{aliquot x } 1000000}$$

3.6.9 Determination of Total Potassium, Calcium and Magnesium

The contents of K, Ca and Mg were measured in a digest obtained by treating samples with selenium catalyst and sulfuric acid (As shown in phosphorous digestion above).

3.6.9.1 Total Potassium

The standard potassium solutions were prepared as follows: 1000ppm of stock solution was prepared by weighing 1.907 g of dried potassium chloride (KCl) into 1000ml of distilled water. 100ppm working solution was made from 1000ppm solution by diluting 20ml from stock solution to 200ml with distilled water. 0, 1, 2, 4, 6, and 8 mL of the standard K solution above were pipetted into 100 mL volumetric flasks. 3ml of 1N sulfuric acid was added to each solution and made to 100ml with distilled water. Five (5) ml of the digest solutions was measured into 50ml volumetric flasks. starting with standards, the solutions were sprayed directly into the flame of the flame photometer for readings. Calibration curve was prepared by plotting the absorbance readings against potassium concentrations in the standard samples and the concentration of potassium present in the samples solution was determined. The concentration of potassium expressed in percent was calculated as follows:

$$K\ (\%) = \frac{(a - b) \times v \times f \times 100}{1000 \times w \times 1000}$$

where a = concentration of potassium in the digest;

b = concentration of flask of the blank digest;

w = the weight of sample;

v = volume of the digest solution and

f = dilution factor

3.6.9.2 Calcium

The standards Calcium solutions were prepared as follows: 1000ppm of stock solution was prepared by weighing 2.497g of calcium carbonate ($CaCO_3$) into 1000ml of distilled water. 500ppm working solution was made from 1000ppm solution by diluting 50ml from stock solution to 100ml with distilled water. 0, 1, 2, 4, 5, and 6 mL of the standard Calcium solution above were pipetted into 100 mL volumetric flasks to make solutions of 0, 5, 10, 20,25 and 30ppm. The solutions were made to 100ml with distilled water. Five (5) ml of the digest solutions was measured into 50ml volumetric flasks. starting with standards, the solutions were sprayed directly into the flame of the flame photometer for readings. Calibration curve was prepared by plotting the absorbance readings against calcium concentrations in the standard samples and the amount of potassium present in the samples solution was calculated from the standard equation.

$$Ca\ (\%) = \frac{(a-b)\times v\times f\times 100}{1000\times w\times 1000}$$

where a = concentration of Calcium in the digest;

b = concentration of flask of the blank digest;

w = the weight of sample;

v = volume of the digest solution and

f = dilution factor

3.6.9.3 Magnesium

The standards Magnesium solutions were prepared as follows: 1000ppm of stock solution was prepared by weighing 1g of spec-pure magnesium rod and dissolved in 30 ml of 1N nitric acid HNO_3 and made to 1000ml mark with distilled water. A 50ppm working solution was made from 1000ppm solution by diluting 10ml from stock solution to 200ml with distilled water. A 0, 0.5, 1, 2,4, 8 and 10 mL of the standard Magnesium solution above. Four (4) ml of $1NH_2SO_4$ was added to each flask and made up to mark with distilled water provides a series of standards containing 0, 0.25, 0.5, 1.0, 2.0, 4.0 and 5.0 mgL^{-1}, respectively. Five (5) ml of the digest solutions was measured into 50ml volumetric flasks and filled to a 50ml mark with distilled water. starting with standards, the solutions were sprayed directly into the flame of the Atomic Absorption Spectrophotometer for readings. Calibration curve was prepared by plotting the absorbance readings against calcium concentrations in the standard samples and the amount of potassium present in the samples solution was calculated from the standard equation.

$$\text{Mg}(\%) = \frac{(a-b)\times v\times f\times 100}{1000\times w\times 1000}$$

where a = concentration of Magnesium in the digest;

b = concentration of flask of the blank digest;

w = the weight of sample;

v = volume of the digest solution and

f = dilution factor

3.6.10 Determination of Lignin and Cellulose

Lignin was determined using Acid Detergent Fiber (ADF) prepared following the method of Van Soest, (1963). One gram of oven dried sample (Wg) was transferred into a beaker (Tall form) for refluxing. Acid detergent solution was added to the beaker in which sample is taken. The contents were heated to boiling, heat was reduced when it started boiling and refluxed for 60 minutes. The contents of the beaker were filtered using suction into a pre-weighed glass sintered crucible (Yg). The contents were washed four times with hot distilled water (100ºC) followed by acetone until it removed no more color. The contents of the crucible were dried overnight at 100ºC and the weight of the crucible with content was recorded (X g) and the ADF contents was calculated as follows:

$$\text{ADF}(\%) = \frac{(Xg-Yg)}{Wg}\times 10$$

To the crucible containing the ADF; 15ml of 72% sulfuric acid was added and kept in a petri dish for 3 hours. The contents of the crucible were stirred every 30 minutes and sulfuric acid was added whenever necessary. The content was filtered and washed with distilled water until its free from the acid. The crucible containing the residues was oven dried overnight at 105ºC and weighed

(S1g). the contents were ashed in the furnace at 510ºC. The content was removed in furnace, cooled in a desiccator and weighed (Sg) and the lignin and cellulose contents were calculated as follows:

$$\text{Lignin (\%)} = \frac{(S1g - Sg)}{Wg} \times 100$$

Cellulose (%) = ADF (%) –Lignin (%)

3.6.11 Determination of Polyphenols

Half a gram of each sample was added into oven dried McCartney bottles. 20 ml of 100% ethanol was added and shaken. The bottles were covered with Aluminium Foil and allowed to stand for 24 hours. After the 24-hour period, the sample in solution was filtered and the Extract of each plant harvested were analyzed for phenolic compounds using the Folin-Ciocalteu method (Singleton, 1999). Two (2) ml of each extract were measured with a measuring cylinder and then diluted to 20 ml with distilled water in test tubes. Twenty (20) µl of the diluted samples were pipetted into cuvettes; 1.58 ml of distilled water and 100µl of Folin-Ciocalteu reagent were added respectively into the solution and shaken to mix. A 300 µl of Sodium carbonate was added to the solution after about 5 minutes and shaken. The solution was placed in an oven for 30 minutes at a temperature of 40°C. The cuvettes were taken out after the 30 minutes and allowed to stand until it cooled.

The absorbance at 765 nm was determined against the blank (ethanol) using the visible spectrophotometer. The concentration for the phenolic compounds was determined from the standard curves of linear equations.

3.7 Data analysis

Statistical Package for Social Sciences (SPSS) software version 21.0 and Microsoft Excel (2016) were used to process the qualitative data collected. The descriptive statistics: frequencies and percentages were used. Tables, bar graphs and pie charts were used to represent the data. The data from gases emissions and nutrient release patterns experiments were first analyzed by two-way analysis of variance (ANOVA) to analyze the effect of time and treatments on N, P, K, Ca^{2+} and OC mineralization. Then analyzed by one-way ANOVA to analyze the effect of treatment on N, P, K, Ca^{2+} and OC mineralization at a given time using GenStat 12^{th} Edition statistical package PL 20.1 (VSN International Ltd). Significant differences among the means were assessed with the Least Significant Difference (LSD) test at 5% probability levels.

CHAPTER FOUR

RESULTS

The results section consists of two sections, namely; results on the questionnaires from the farmers on the management of the organic agricultural wastes in the Kwaebibirem district. The second section of the results is on the laboratory incubation experiments on nutrient release patterns, carbon dioxide and ammonia emissions from various treatments of organic agricultural wastes.

4.1 Demographic characteristics of the Respondents

A total of 175 questionnaires were administered to the farmer respondents and retrieved. The results of the survey showed that majority of the respondents were males, representing 65.1% of the total participants. As shown in table 4.1, The majority of the respondents (75.43%) were within the age group of 45 years & above. Respondents within the age group of 15-24 years formed the least 1.14% while the age ranges 25-34 years and 35-44 years constituted 4% and 19.43% respectively. About 72.6 % have basic education, 11.4 % had no formal education, while 9.7 and 6.3% had secondary and tertiary education respectively. With respect to years of farming experience, the majority (46.3%) had farmed 16-30 years while 32.0, 18.3 and 3.4% had farmed 1-15 years, 31-45 years and over 45years respectively.

The results further showed that the most important crops that are grown are cash crops mainly cocoa and oil palm. Other crops such as cassava, rice, maize, plantain, citrus and vegetables are also grown in addition to these cash crops.

Table 4. 1 Detailed demographic characteristics of the respondents (n= 175)

Variables	Frequency (F)	Percentage (%)
Gender		
Male	114	65.1
Female	61	34.9
Age		
15-24 years	2	1.14
25-34 years	7	4
35-44 years	34	19.43
45 years & above	132	75.43
Education		
No Formal Education	20	11.4
Basic	127	72.6
Secondary	17	9.7
Tertiary	11	6.3
Number of years in Farming		
1-15 years	56	32
16-30 years	81	46.3
31-45 years	31	18.3
46 years & above	6	3.4
Land Ownership		
Family land	74	42.3
Freehold	47	26.9
Rents the land	7	4.0
Share cropping	47	26.9
Farming Method		
Traditional	161	92
Mechanized	3	1.7
Semi-Mechanized	11	6.3
Type of Farming		
Subsistence	4	2.3
Commercial	117	66.9
Combined purpose	54	30.9
Important crop grown		
Cocoa only	26	14.9
Oil Palm only	13	7.4
Cocoa and Oil palm	60	34.3
Cocoa, Oil palm and others	76	43.4

Where n = sample size

4.2 Major agricultural wastes generated within the study area and their current management practices/uses by farmers

According to the farmers; The major agricultural wastes generated are classified into two groups, crop residues and animal wastes. The crop residues are cocoa pod husks, various wastes from palm fruits namely- empty fruit bunches, palm kernels and palm oil mill effluents (POME); rice husks and straws and corn stalks. Cassava and plantain peels are also present in minute quantities. The majority of animal wastes generated in the district are poultry and goat manure followed by sheep, cattle and pigs.

Figure 4.1 presents the results on how the farmers perceive the occurrence of the agricultural wastes in the community; 31% responded that the occurrence of the wastes is a major problem whilst 36 % responded that it is a minor problem and the remaining 33% responded that the waste is not a problem in the community. Those who responded that the waste is a problem in the community are the farmers that are in the vicinity of palm oil mills and the challenges mentioned are the problem of mosquitoes' infestation, stream water pollution and bad odor from the wastes.

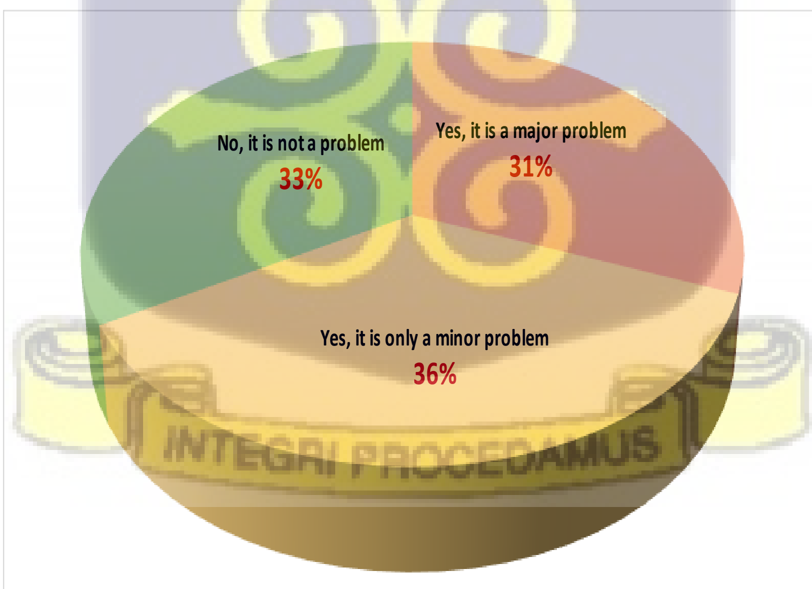

Figure 4. 1 Farmer's perception on agricultural wastes as a problem in the community

The study assessed the farmers' perception on the usefulness of the wastes generated in the study area. As shown in the Fig.4.2, the responses on whether the wastes are beneficial/useful for the farmers showed that by a half of the respondents (54.3%) perceive the wastes as useful whereas the remaining 45.7% perceive the waste as not useful. Those who responded that the wastes are useful mentioned reuse on the crop farms as the main use of the wastes.

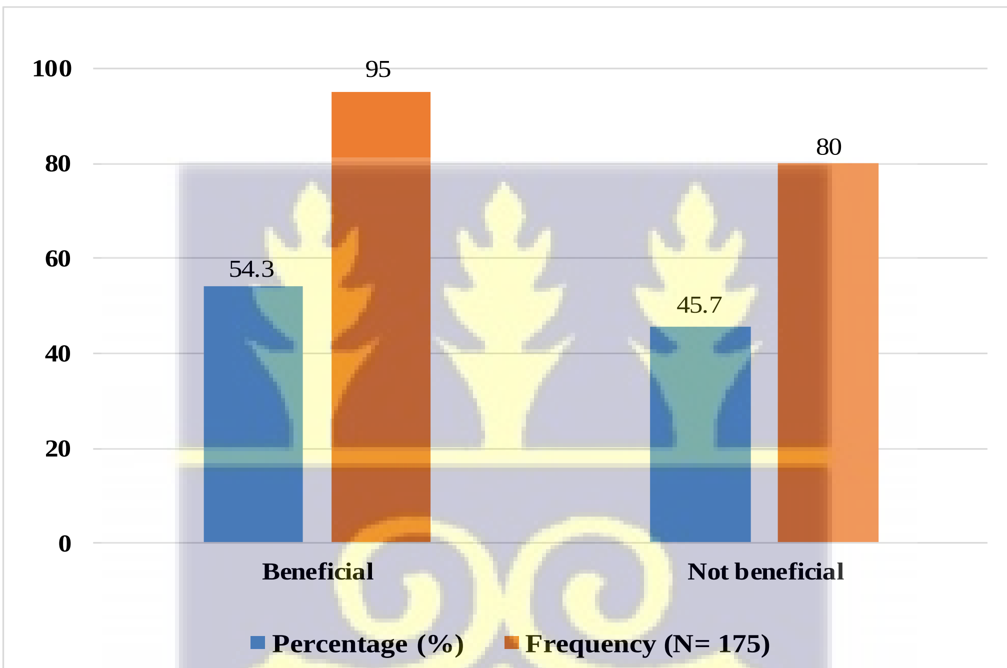

Figure 4. 2 Farmers' perception on the usefulness of agricultural wastes generated within the study area

Figure 4.3 and 4.4 shows the farmers management practices of the previously mentioned agricultural wastes. For the crop residues, 117 farmers (66.9%) of all respondents recycle the wastes in the crop farms; Among these farmers that recycle the wastes; some compost the residues before use, others produce biochar from the wastes while the majority reuse the crop residues in their farm as obtained or chopped the waste into smaller sizes. 5.7% of all the respondents apply the wastes as mulch in their plantation for the purpose of retaining the soil moisture and suppressing weeds growth. 41 farmers (23.4%) indiscriminately dump outside/ throw away the wastes whilst 17 farmers (9.7%) incinerate the wastes. Among the 95 farmers who constitute 54.3% of the total respondents who reuse the crop residues in their farms, only 86 farmers (81%) understand the benefits of using crop residues on farm while the remaining 18 respondents (19%) do it because others do so.

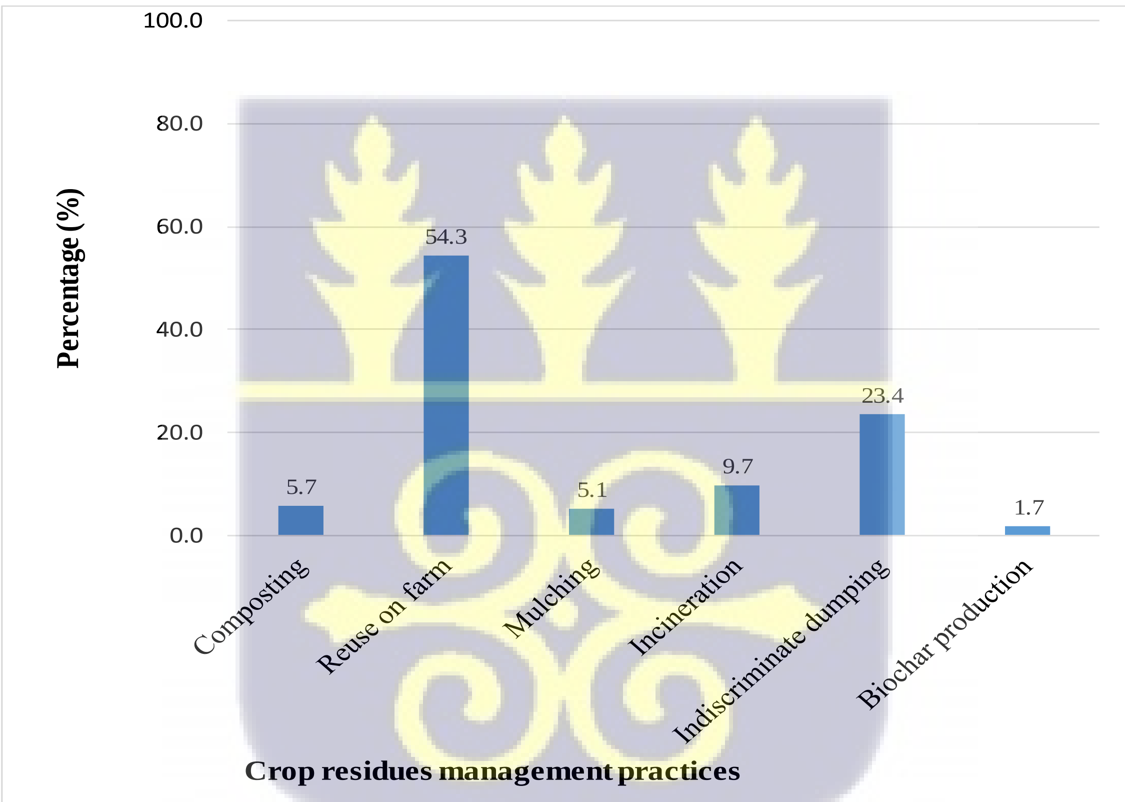

Figure 4. 3 Crop residues management practices options by farmers in the study area

Of the 175 respondents, only 118 farmers (67.4%) rear animal/livestock and the management practices of those animal wastes are presented in fig.4.4. The majority (55.1%) of farmers throw the wastes at any open place or bury the wastes (4.2 %) while others spread on crop farms (40.7%).

There were a number of reasons given for the disposal of animal wastes. Those who use the wastes on crop farms do so to improve soil fertility. Those who throw away the waste; (82%) of them consider the wastes as not useful whilst the rest know that the wastes improve soil fertility but transportation to the farm is a challenge. Burying the wastes in the ground was used due to lack of nearby space to dump the waste, hence bury the wastes to prevent bad odor.

The farmers were also assessed on how they store the animal wastes before use or disposal; The majority (92.4%) responded that they store the wastes as a heap near the animal shed, 4.2% pack the wastes in the sacs/bags whilst the remaining 3.4% bury the wastes in the ground.

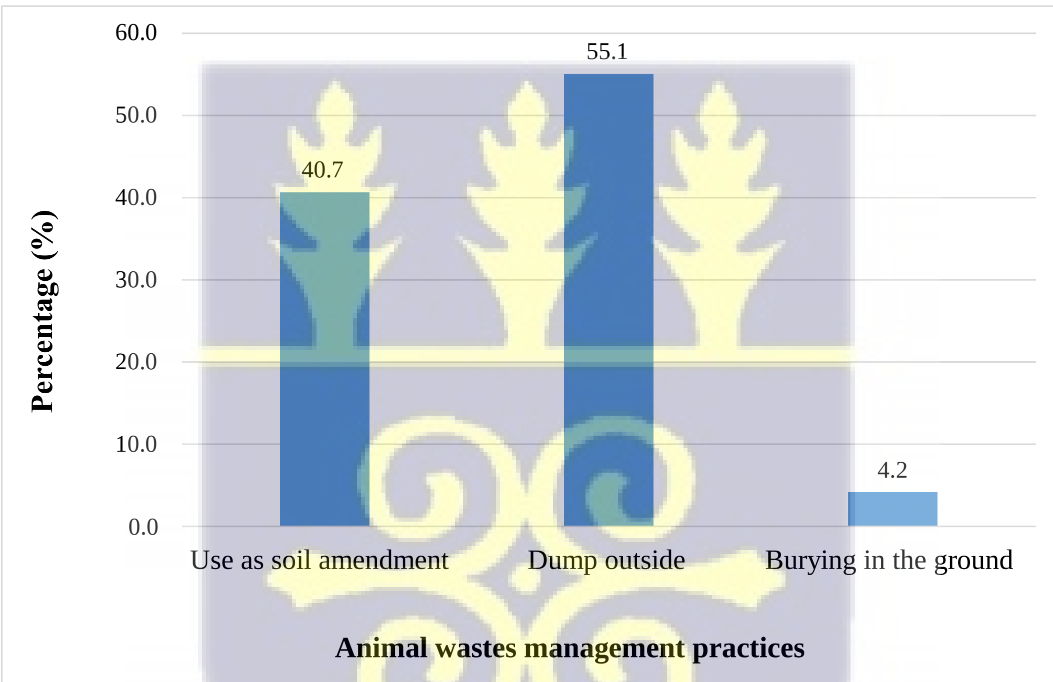

Figure 4. 4 Animal wastes management practices options by farmers within the study area

4.3 Farmers Knowledge and Perception on sustainable management of agricultural wastes

Results on the farmer's opinions on how the wastes should be managed sustainably showed that 56.6% have knowledge that the organic wastes contain plant nutrients and should be used as soil amendment, 25.1% responded that the they don't have any idea whereas 9.1, 8.0 and 11% responded to burn the wastes, dump the wastes to landfill and to bury the wastes respectively.

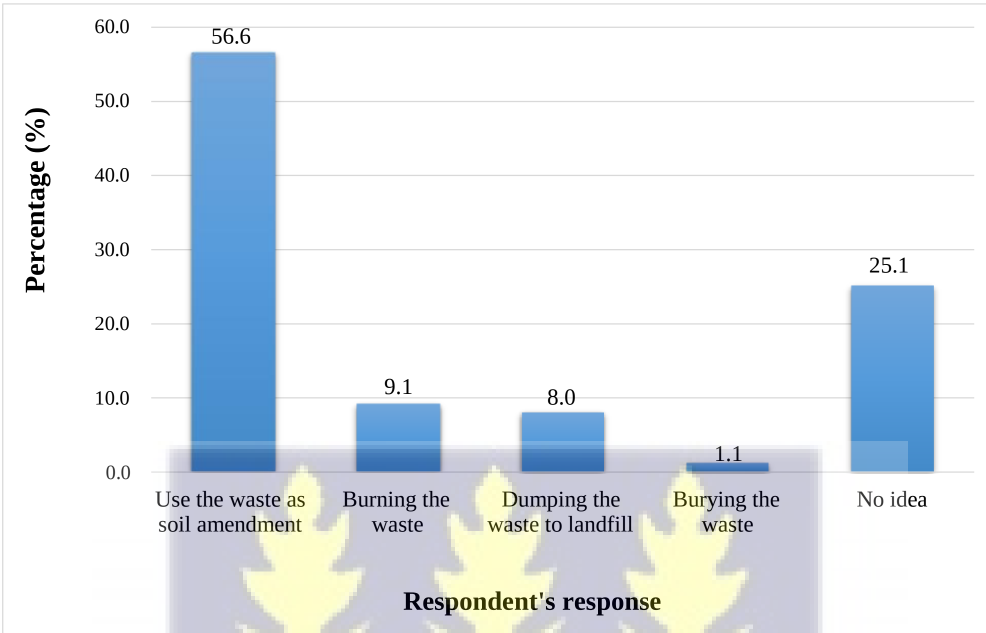

Figure 4. 5 Respondent's opinions on the sustainable management of agricultural wastes

As shown in figure 4.6, the study revealed that 71% of the respondents were aware that improper disposal of agricultural wastes causes environmental problems including the impairment of air quality due to greenhouse gases emissions and affects water quality as a result of water runoff when it heavily rained.

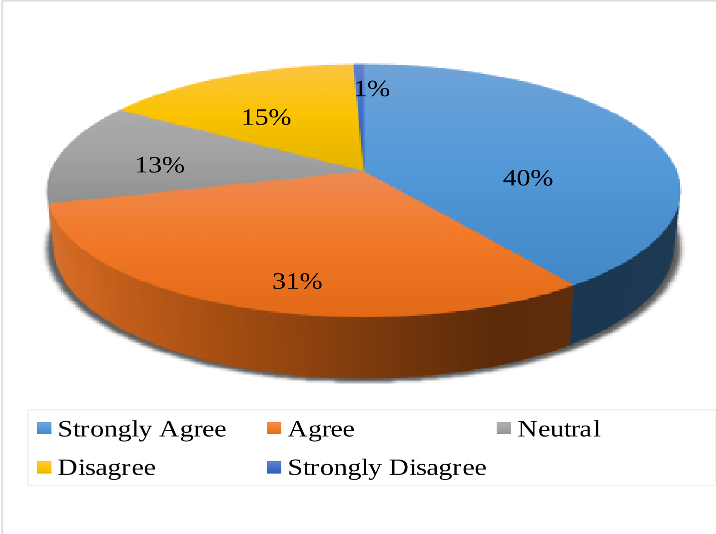

Figure 4. 6 Farmer's perception on the environmental challenges caused by inappropriate management of agricultural wastes

The study revealed that 51% strongly agree while 34% agree to the statement that reusing and recovering agricultural wastes on farm improves the soil fertility. Eleven percent of the respondents are uncertain while 4% disagree with the statement (Figure 4.7).

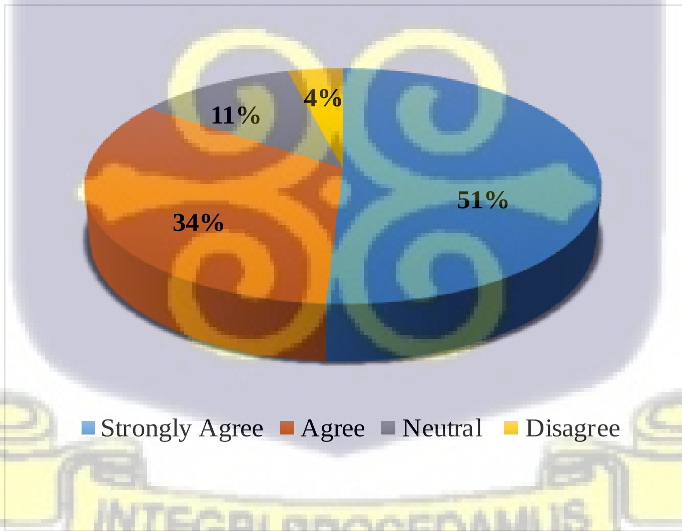

Figure 4. 7 Farmer's perception on the benefits of reusing and recovering nutrients from agricultural wastes on farm

As shown in figure 4.8, The respondent's perception on drudgery/labour intensiveness of reusing and recovering agricultural waste on farm shows that only 19% perceive the reuse of agricultural waste as not laborious whilst the majority (70%) perceive the reuse of agricultural waste as laborious. The remaining 11% were neutral to the opinion.

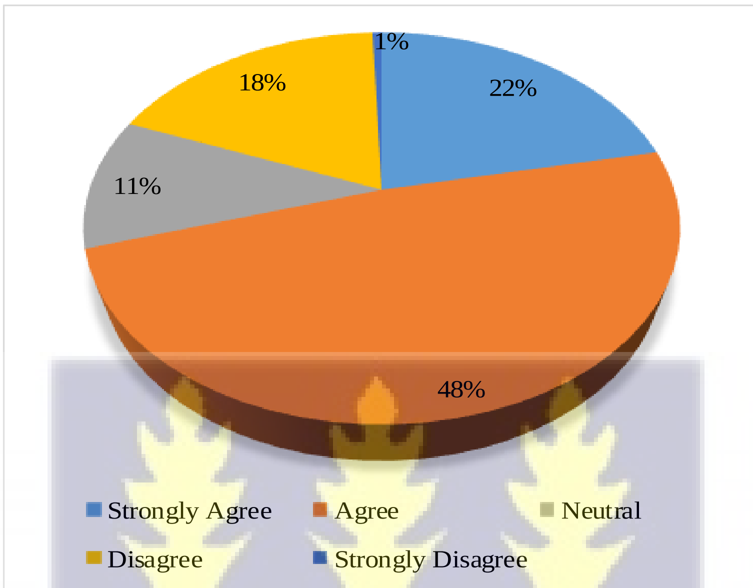

Figure 4. 8 Farmer's perception on laboriousness of reusing and recovering agricultural wastes on farm

Composting is among the effective and sustainable ways of managing organic wastes. The study assessed the level of knowledge on composting as a sustainable waste management strategy. The results, as shown in Fig. 4.9, shows that 66% of the respondents understands that composting is an effective way of managing agricultural wastes which eliminates environmental challenges as well as financial costs associated with transportation. While 32% of the respondents are uncertain to the concept of using agricultural wastes in composting, the remaining 2% disagree with this method of agricultural waste management.

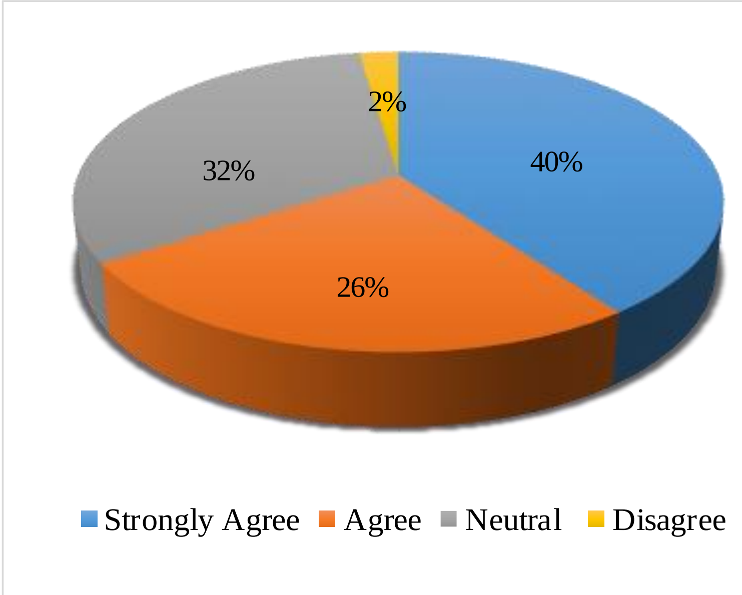

Figure 4. 9 Farmers perception on composting as a sustainable waste management strategy

Recently, interest in using biochar in managing agricultural wastes have increased due to the perceived role it plays in soil fertility management and solving environmental problems such as climate change mitigation. The respondents have a little knowledge on the role of biochar production as a sustainable strategy of organic waste management. Figure 4.10 shows that only 18% of the respondents have knowledge that biochar production from agricultural wastes reduces the wastes volume and eliminates other harmful residues. Furthermore, only 16% of the respondents understands that biochar improves soil health (Fig.4.11).

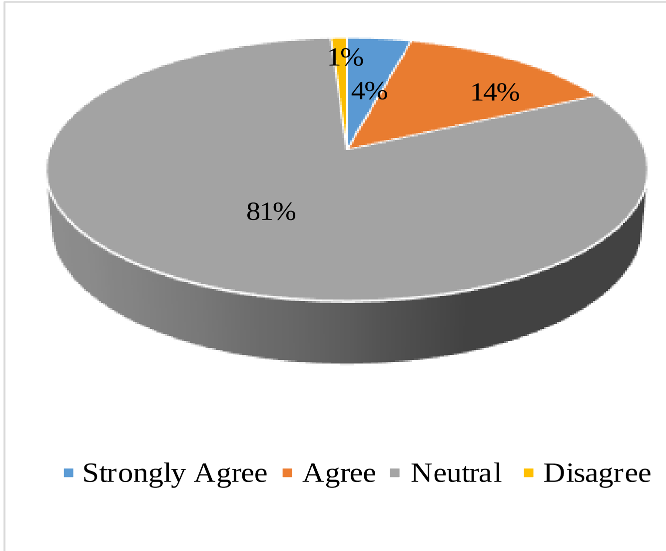

Figure 4. 10 Farmers perception on biochar production as a sustainable waste management strategy

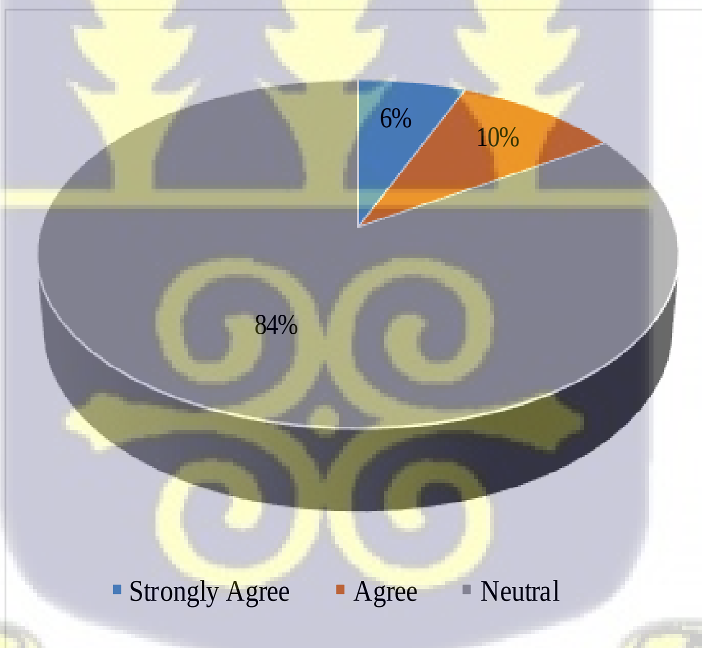

Figure 4. 11 Farmers perception on using biochar to improves soil health and combat climate change

4.4. Farmer's knowledge on the environmental challenges of using fertilizers

The study also assessed the farmer's knowledge on the environmental effects of using organic or inorganic fertilizers. About a half of the farmers; that is 48.1% are aware of the negative environmental impacts of using inorganic fertilizers (Fig.4.12). The most challenges mentioned includes water pollution, air pollution and soil compaction. The other challenges mentioned by the farmers includes harmful to human health and soil biodiversity and reduction of soil fertility due to continuous use of inorganic fertilizers.

On the other side for the organic fertilizers, only 7.4% of the respondents are aware that using organic fertilizers can also cause negative effects to the environment (Fig.4.12) and the challenges mentioned were water and air pollution as well as land deterioration if the fertilizer is applied in large quantities. Fungi infestation and rapid weeds growth were also mentioned.

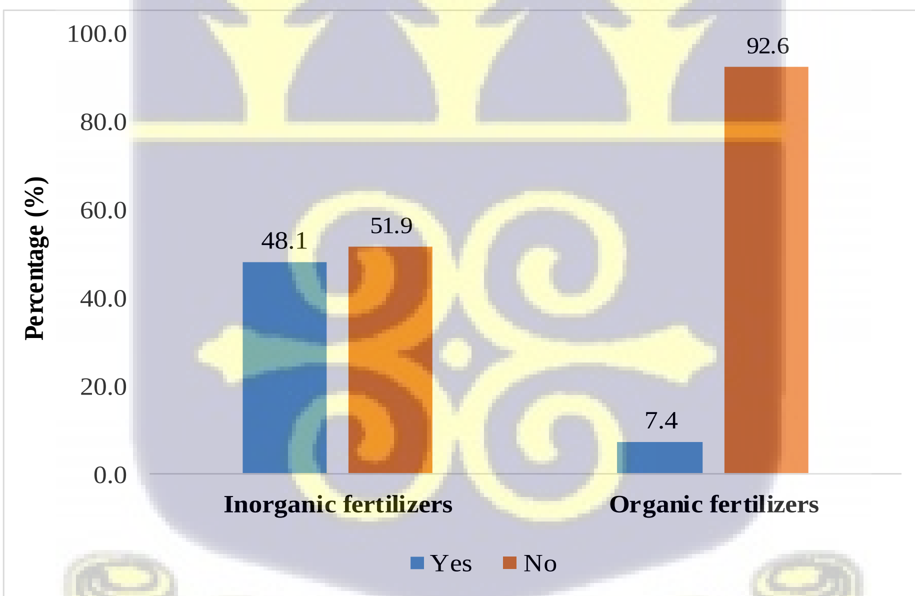

Figure 4. 12 Farmer's knowledge on the environmental challenges of using fertilizers

4.5 Characteristics of the soil used in the experiments

The particle size distribution of the soil showed 40% sand, 48% silt and 12% clay. The pH (1:2, soil: H_2O) was 6.49. Table 4.2 shows the details on the physico-chemical characteristics of the soil used in this study.

Table 4. 2 Physico-chemical properties of the soil used in the study

Parameters	Soil
Sand (%)	40
Silt (%)	48
Clay (%)	12
Textural class	Loam
pH (1:2, soil: water)	6.49
Moisture content (%)	13.58
Electrical conductivity (dS/m)	0.15
Cation Exchange Capacity ($cmol_c$/kg)	8.52
Bulk density (g/cm^3)	1.15
Organic carbon (%)	1.19
Total Nitrogen (%)	0.14
Phosphorous (%)	0.32
Potassium (%)	0.02
Calcium (%)	0.09
Magnesium (%)	0.05

4.6 Characteristics of organic residues (EFB, CPH, RH and PD) used in the experiments

Table 4.3 shows some chemical properties of organic residues used in this study. Poultry droppings has the lowest pH (6.6) while cocoa pod husks have the highest pH (9.3). Cocoa pod husks had higher organic carbon, total nitrogen, potassium, calcium and polyphenols as compared to empty fruit bunches. Rice husk biochar had lowest nitrogen, phosphorous and calcium contents but highest organic carbon. Table 4.3 shows the details on the chemical characteristics of the organic residues used in this study.

Table 4. 3 Chemical properties of organic residues used in this study's experiments

Parameters	EFB	CPH	PD	RHB
pH	8.9	9.3	6.6	8.02
DM (%)	91.49	87.76	–	–
TOC (%)	38.4	39.04	30.88	36.73
OM (%)	66.05	67.15	29.58	–
Total Nitrogen (%)	1.19	1.55	2.77	0.48
C/N ratio	32.31	25.25	11.15	76.52
Phosphorous (%)	0.22	0.17	2.60	0.16
Potassium (%)	2.18	3.28	1.78	1.02
Calcium (%)	0.38	0.43	0.28	0.15
Magnesium (%)	1.06	0.97	0.58	0.30
Lignin (%)	30.25	20.97	–	–
Lignin/N ratio	43.06	26.05	–	–
Polyphenols (GAE/g)	29.34	47.9	–	–
Cellulose (%)	43.06	26.05	–	–

–: not determined

4.7 Effect of organic residues type and particle size on CO_2 emission

The type and particle size of the organic residue influenced CO_2 emissions. Variations were observed throughout the incubation period of 120 days. The control which was only the unamended soil recorded the lowest amount of CO_2 emitted throughout the incubation period and the cumulative CO_2 emitted from the control after 120 days of incubation was 5.71mg g^{-1}soil. The average cumulative CO_2 emissions from all EFB and CPH treatments ranged from 310.95 to 366mg CO_2/g residue.

4.7.1 Cumulative carbon dioxide emissions

Figure 4.13 presents the results on the effect of organic residue type and particle size on cumulative CO_2 emissions after 120 days of incubation. The cumulative CO_2 emissions of EFB and CPH were not significantly different except for the smallest particle sizes, EFBS3 and CPHS3. CPHS3 emitted significantly higher CO_2 than EFBS3. The average cumulative CO_2 emitted from CPHS3 and EFBS3 were 366.04 and 350.70mg CO_2/g respectively.

The particle size of EFB and CPH significantly affected the cumulative CO_2 emissions in a similar trend; CO_2 emissions increased with the decreasing particle size. The cumulative CO_2 emissions from EFB increased in the order EFBS1<EFBS2< EFBS3 and the average cumulative CO_2 emitted was 310.95, 326.04 and 350.70mg CO_2/g for EFBS1, EFBS2 and EFBS3 respectively. The cumulative CO_2 emissions from CPH increased in the order CPHS1<CPHS2< CPHS3 and the average cumulative CO_2 emitted was 313.55, 337.73 and 366.04mg CO_2/g for CPHS1, CPHS2 and CPHS3 respectively.

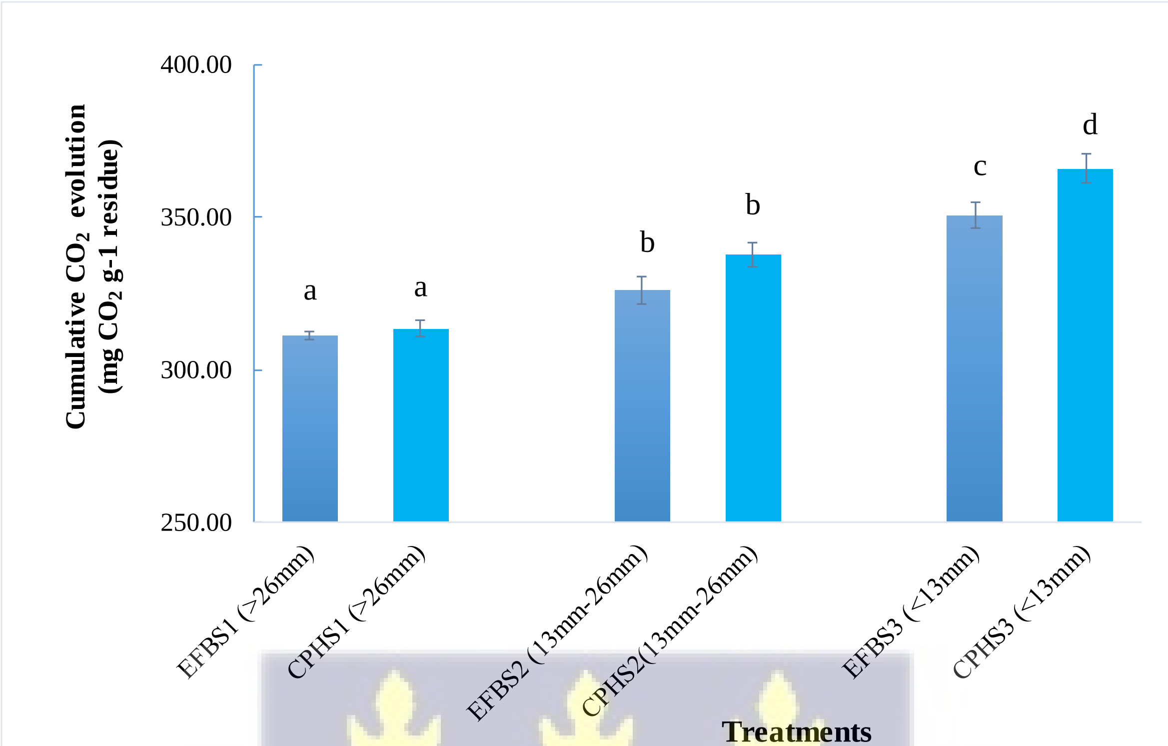

Figure 4. 13 Cumulative Carbon dioxide released from EFB and CPH of different particle sizes. Means with the same letter are not significantly different from each other ($p>0.05$). Vertical bars indicate ± standard error of the mean of the observed values.

4.7.2 Dynamics of carbon dioxide emissions

4.7.2.1 Empty fruit bunches

The emissions of CO_2 in EFB changed with time. The changes in CO_2 emissions from three different particle sizes of EFB is presented in Fig.4.14. The highest CO_2 emission from EFB recorded was at 24th day for EFBS1 (22.60mg CO_2/g residue) and 20th day for EFBS2 (24.66mg CO_2/g residue) and EFBS3 (31.44mg CO_2/g residue).

Generally, there was a steep rise in CO_2 emission from day 2 to day 20 for all particle sizes. During this period, there was significant difference ($p<0.05$) in CO_2 emissions among the particle sizes.

The CO_2 emissions increased with decreasing particle size. After this period, i.e from 20th /24th to 72th day, the CO_2 emissions rate decreased for all the three EFB particle sizes. The difference in cumulative CO_2 emissions were maintained among the three sizes and the amount of CO_2 evolved remained higher for EFBS3. From day 72 to the end of experiment; the trend was reversed in a way that EFBS1 emitted significantly higher amount of CO_2 than EFBS2 and EFBS3. No significant difference was observed between the EFBS2 and EFBS3 in the cumulative CO_2 emissions in that period.

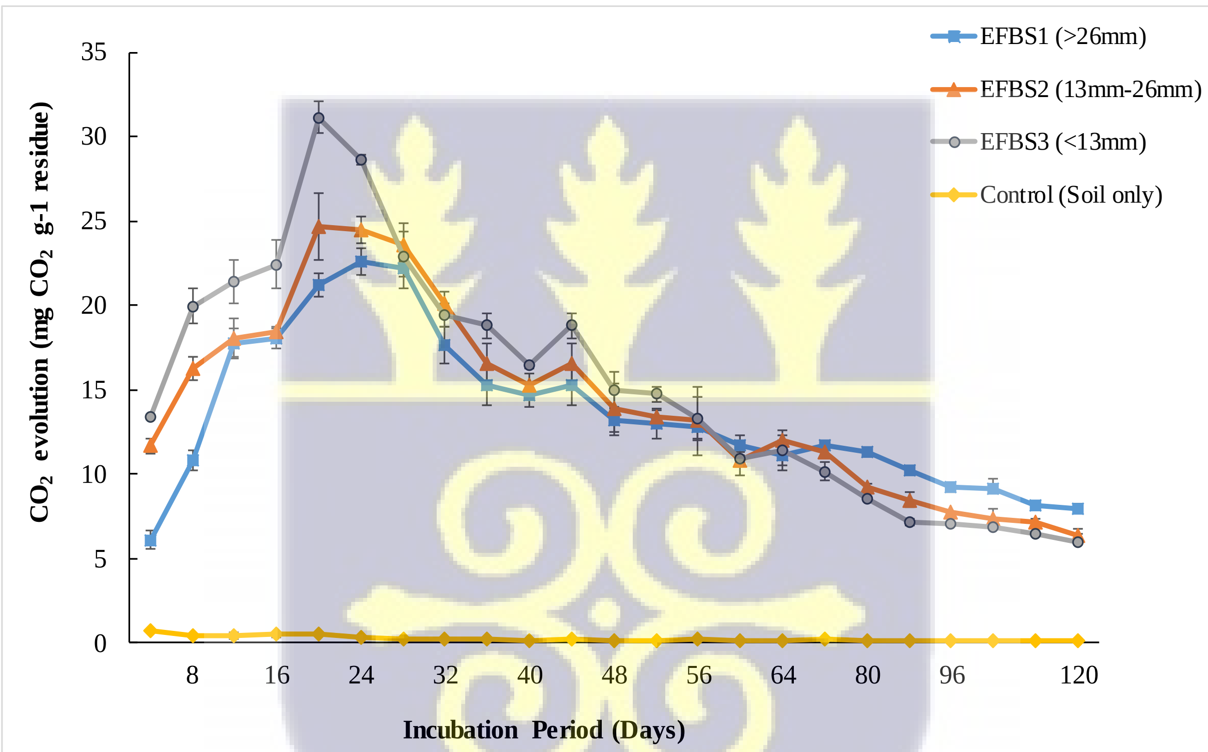

Figure 4. 14 Changes in carbon dioxide emissions as effected by particle sizes of empty fruit bunches. Vertical bars indicate ± standard error of the mean of the observed values (n=3).

4.7.2.2 Cocoa pod husks

The emissions of CO_2 in CPH showed several variations throughout the incubation period. Fig.4.15 shows the changes in CO_2 emissions as affected by particle sizes of CPH. There was a steady rise in CO_2 emissions from day 2 to day 20 for all sizes. During this period, the particle size influenced the amount of CO_2 emitted in a way that the larger the particle size, the lower the CO_2 emitted. The maximum peaks of CO_2 emitted from CPH recorded was at 20th day for CPHS1 (23.04mg CO_2/g residue) and CPHS3 (27.30mg CO_2/g residue) whilst CPHS2 had the maximum peak (24.98mg CO_2/g residue) at 16th day of incubation period.

From 20th onwards, there was a decrease in CO_2 emissions for all particle sizes. From 20th to 32th day, the rate of microbial respiration was similar for the three CPH particle sizes i.e. the difference in CO_2 emissions were not significantly different among the three particle sizes.

From 36th to 44th day, the CPHS2 recorded the highest amount of carbon dioxide as compared to CPHS1 and CPHS3, although the difference was statistically significant for only CPHS3. After this period CPHS2 showed the lowest CO_2 emissions until day 64. From day 72 to the end of experiment; the trend was similar to the initial stage i.e. t the larger the size, the lower CO_2 emitted.

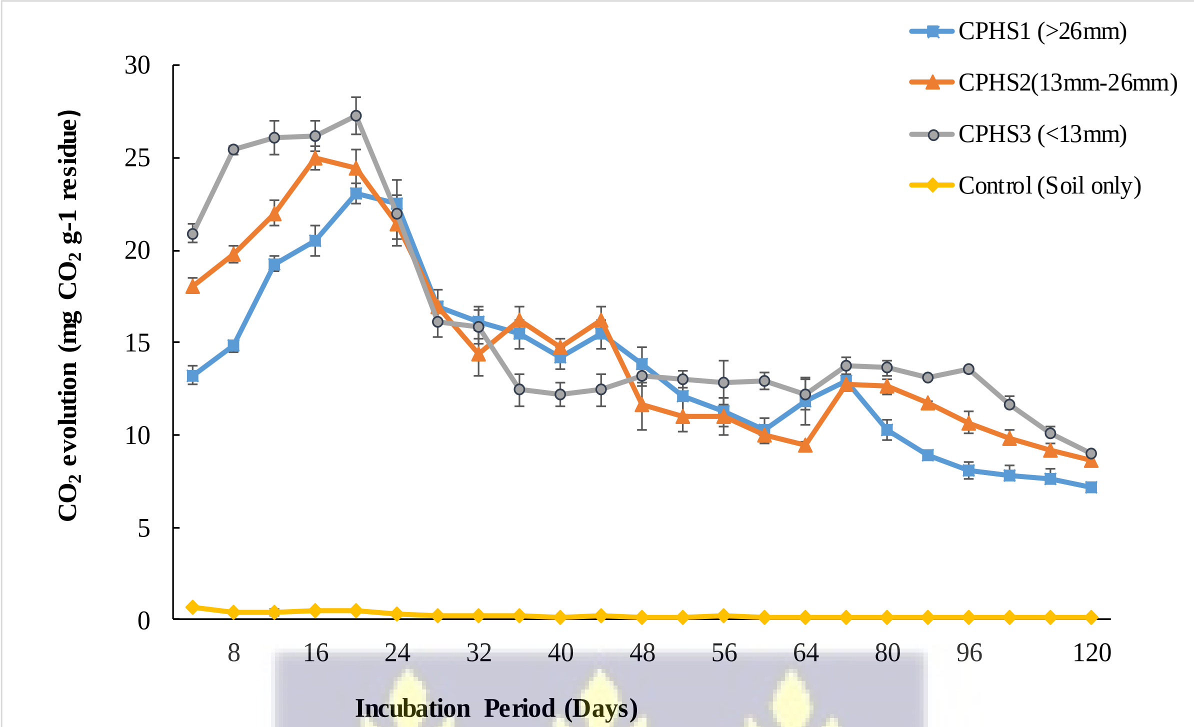

Figure 4. 15 Changes in carbon dioxide emissions as effected by cocoa pod husks particle sizes. Vertical bars indicate ± standard error of the mean of the observed values (n=3)

4.8 Effect of organic residues type and particle size on decomposition and nutrient release

4.8.1 Effect of organic residue type and particle size on decomposition

4.8.1.1 Mass loss

The non-linear regression showed that the decomposition of the EFB and CPH followed the exponential model ($W_t=W_0\, e^{-kt}$). As shown in Table 4.4 & 4.5, CPH decomposed faster than EFB throughout the incubation period, although the difference was statistically insignificant ($p>0.05$).

Table 4. 4 Percent dry matter weight remaining of empty fruit bunches and cocoa pod husks during the incubation period of decomposition

Organic residue	S1 (>26mm)	S2 (13-26mm)	S3 (<13mm)
	2 WEEKS		
EFB	91.68±2.38[a]	89.80±1.92[a]	90.30±1.06[a]
CPH	89.07±3.12[a]	88.57±1.11[a]	87.60±2.08[a]
	4 WEEKS		
EFB	78.68±1.34[a]	81.95±1.59[a]	77.59±2.34[a]
CPH	80.31±2.55[a]	79.91±2.4[a]	77.38±1.72[a]
	8 WEEKS		
EFB	73.29±1.42[a]	70.93±0.99[a]	67.95±1.05[a]
CPH	70.05±4.18[a]	68.34±3.16[a]	64.98±2.86[a]
	12 WEEKS		
EFB	69.59±1.88[a]	67.92±2.01[a]	64.21±3.03[a]
CPH	64.94±2.67[a]	61.14±3.00[a]	56.96±2.49[a]
	22 WEEKS		
EFB	52.65±1.5[a]	49.63±2.12[a]	44.76±1.17[a]
CPH	48.18±5.04[a]	45.39±3.93[a]	42.35±5.57[a]

The values followed by the same letters within the same column are not significantly different among treatments (p>0.05)

Table 4. 2 Fitted decomposition models of EFB and CPH of different particle sizes

Particle sizes		Crop residue type	
		EFB	CPH
S1(>26mm)	Fitted Models	$98.840e^{-0.030t}$	$91.032e^{-0.030t}$
	R^2	0.93	0.91
	$t_{1/2}$ (weeks)	23.1	23.1
S2 (13-26mm)	Fitted Models	$95.168e^{-0.026t}$	$87.514e^{-0.031t}$
	R^2	0.92	0.89
	$t_{1/2}$ (weeks)	26.7	22.4
S3 (<13mm)	Fitted Models	$93.087e^{-0.032t}$	$87.408e^{-0.039t}$
	R^2	0.92	0.88
	$t_{1/2}$ (weeks)	21.7	17.8

The numerical number on the power of the exponential function is the decay constant (**k**), $\mathbf{R^2}$ is the coefficient of determination, **t** is the time (weeks) in the fitted model and $\mathbf{t_{1/2}}$ is the time (weeks) required for organic residue mass to reduce to half of its initial mass.

Generally, variations in particle sizes of EFB and CPH affected the decomposition in a way that the smaller the particle size, the faster the decomposition (Fig.4.16 & 17). The decomposition of EFB and CPH were significantly higher for EFBS3 and CPHS3 throughout the incubation period. The decomposition rate constant of EFB particle sizes were 0.030, 0.026 and 0.032 for EFBS1, EFBS2 and EFBS3 respectively, whilst that of CPH were 0.030, 0.031 and 0. 039 for CPHS1, CPHS2 and CPHS3 respectively.

At the end of the incubation, the residue left as percent of the initial dry weight of EFB in the order of decreasing particle size were: 52.7, 49.6 and 44.8%, whilst the residue left as percent of the initial dry weight of CPH in the order of decreasing particle size were: 48.2, 45.4 and 42.4% (Table 4.4). In the first four weeks of incubation, the decomposition rate was equivalent for all particle sizes and the dry weight remaining in order of decreasing particle size were 78.7, 82.0 and 77.6% for EFB and 80.3, 80.0 and 77.4% for CPH respectively. In the later stage of decomposition; the dry weight of the smallest sizes decreased significantly faster than that of the two bigger particle sizes for both crop residues (Fig.4.16 & 17). The difference between the middle size and the largest size were not statistically significant except for the last stage of decomposition.

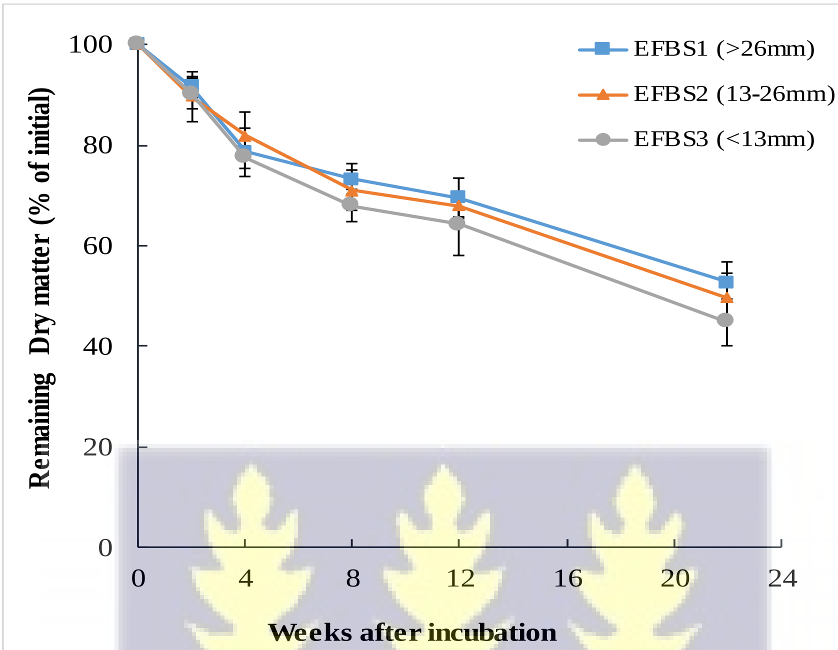

Figure 4. 16 Changes in percent dry matter weight remaining of empty fruit bunches as affected by particle size during the incubation period of decomposition

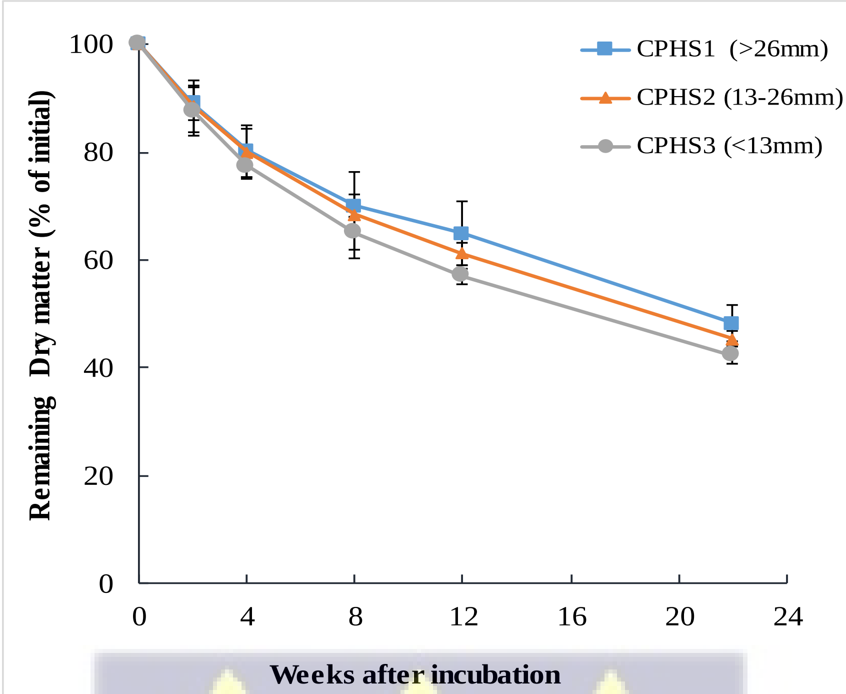

Figure 4. 17 Changes of percent dry matter weight remaining of cocoa pod husks as affected by particle size during the incubation period of decomposition

4.8.1.2 Organic carbon loss

Organic carbon loss seemed to be consistent with mass loss. There was no significant difference in OC remaining in CPH and EFB for all particle sizes. Variations of particle size of EFB affected the OC remaining (Fig.4.18). OC remaining in EFBS3 was significantly lower than OC remained in EFBS1and EFBS2. The percent OC remaining in order of reducing particle sizes were 57.64, 55.56 and 46.39%. There was no significant difference in OC remaining in CPH among all particle sizes throughout the incubation period (Figure 4.19). However, the smaller the particle size, the faster OC mineralization. The percent OC remaining in order of reducing particle sizes were 48.7, 46.8 and 44.5%.

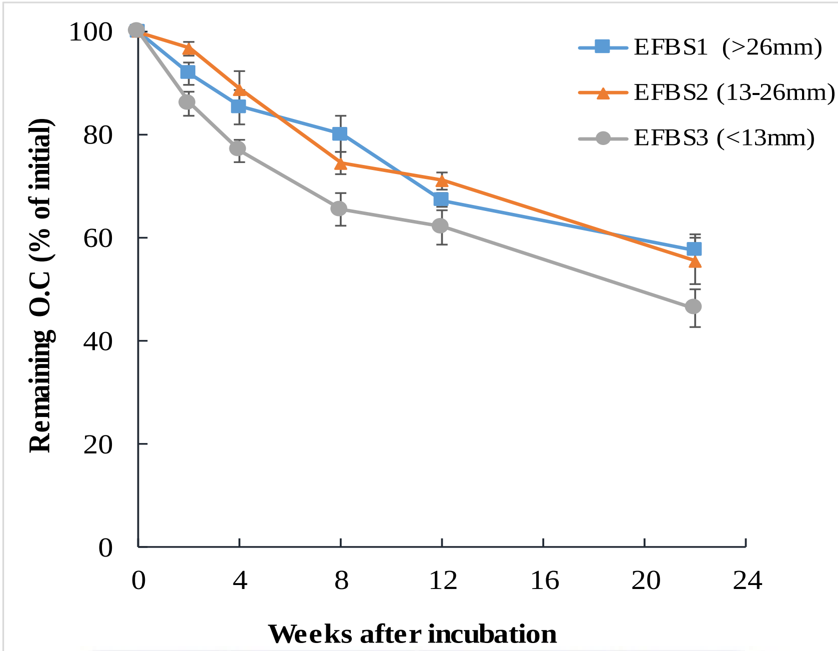

Figure 4. 18 Changes in organic carbon remaining of empty fruit bunches as affected by particle size during the incubation period of decomposition

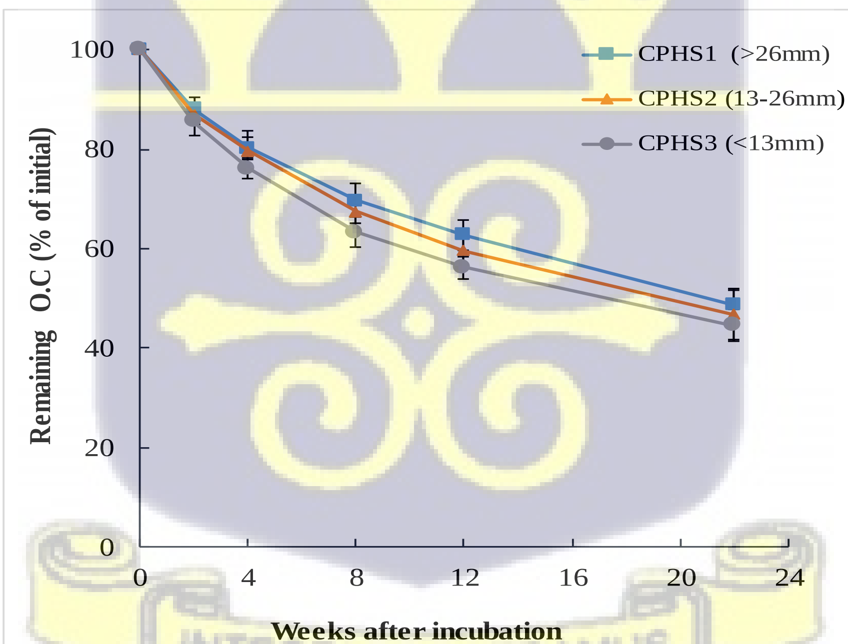

Figure 4. 19 Changes in percent organic carbon remaining of cocoa pod husks as affected by particle size during the incubation period of decomposition

4.8.2 Effect of organic residue type and particle size on nutrients release

4.8.2.1 Effect of organic residue type on nutrients release

Generally, the release of nutrients was affected by the type of organic residue (Table 4.5) although selective and transitory to some extent. There was no significant difference in N and P mineralization of EFB and CPH. CPH released K faster than EFB of the same particle size except for EFBS3 and CPHS3 which showed insignificant difference. CPH released Ca faster than EFB of the same particle size although the difference was statistically significant only for the middle sizes (EFBS2 and CPHS2) as shown in Table 4.5.

Table 4. 6 Percent nutrients remaining of empty fruit bunches and cocoa pod husks after 22 weeks of incubation

Organic residue	**S1** (>26mm)	**S2** (13-26mm)	**S3** (<13mm)
	(% of initial)		
	NITROGEN		
EFB	67.00[a]	61.57[a]	62.89[a]
CPH	63.85[a]	63.63[a]	55.60[a]
	PHOSPHOROUS		
EFB	64.29[a]	57.03[a]	56.30[a]
CPH	66.13[a]	62.13[a]	54.87[a]
	POTASSIUM		
EFB	14.65[a]	14.84[a]	11.52[a]
CPH	24.34[b]	23.52[b]	17.56[a]
	CALCIUM		
EFB	54.35[a]	56.57[a]	46.76[a]
CPH	50.34[a]	46.82[b]	42.02[a]

The values followed by different letters within the same column for each nutrient are significantly different among treatments ($p<0.05$)

4.8.2.2 Effect of organic residue particle size on nutrients release

4.8.2.2.1 Empty fruit bunches

Overall, for all particle sizes of EFB, the nutrients were released in the order K> Ca > P = N at different rates. The changes in the remaining amount of nutrients of EFB as affected by particle size is shown in Figure 4.20. The nitrogen and phosphorous release from EFB followed similar patterns. The release pattern of N was affected by particle sizes although not statistically significant. At the end of incubation, N remaining in EFBS1, EFBS2 and EFBS3 were 67%, 61.6 % and 62.9% of the initial amount respectively whilst the P remaining were 64.3%, 57 % and 56.3%. The mineralization rate constant of N in the order of reducing particle sizes were 0.019, 0.021 and 0.021. while that of P were 0.020, 0.027 and 0.025. The potassium release pattern was affected by particle sizes although spatially. All particle sizes released equivalent amount of K except for the period of (4-8 weeks) after incubation in which significantly higher K was released from EFBS3 than both EFBS1 and EFBS2.

There was no significant difference in calcium release among the particle sizes. However, at the end of incubation (week 22) Ca released from EFBS3 was quite higher than both EFBS1 and EFBS2. The percent Ca remaining in order of reducing particle size were 54.4, 56.6 and 46.8%

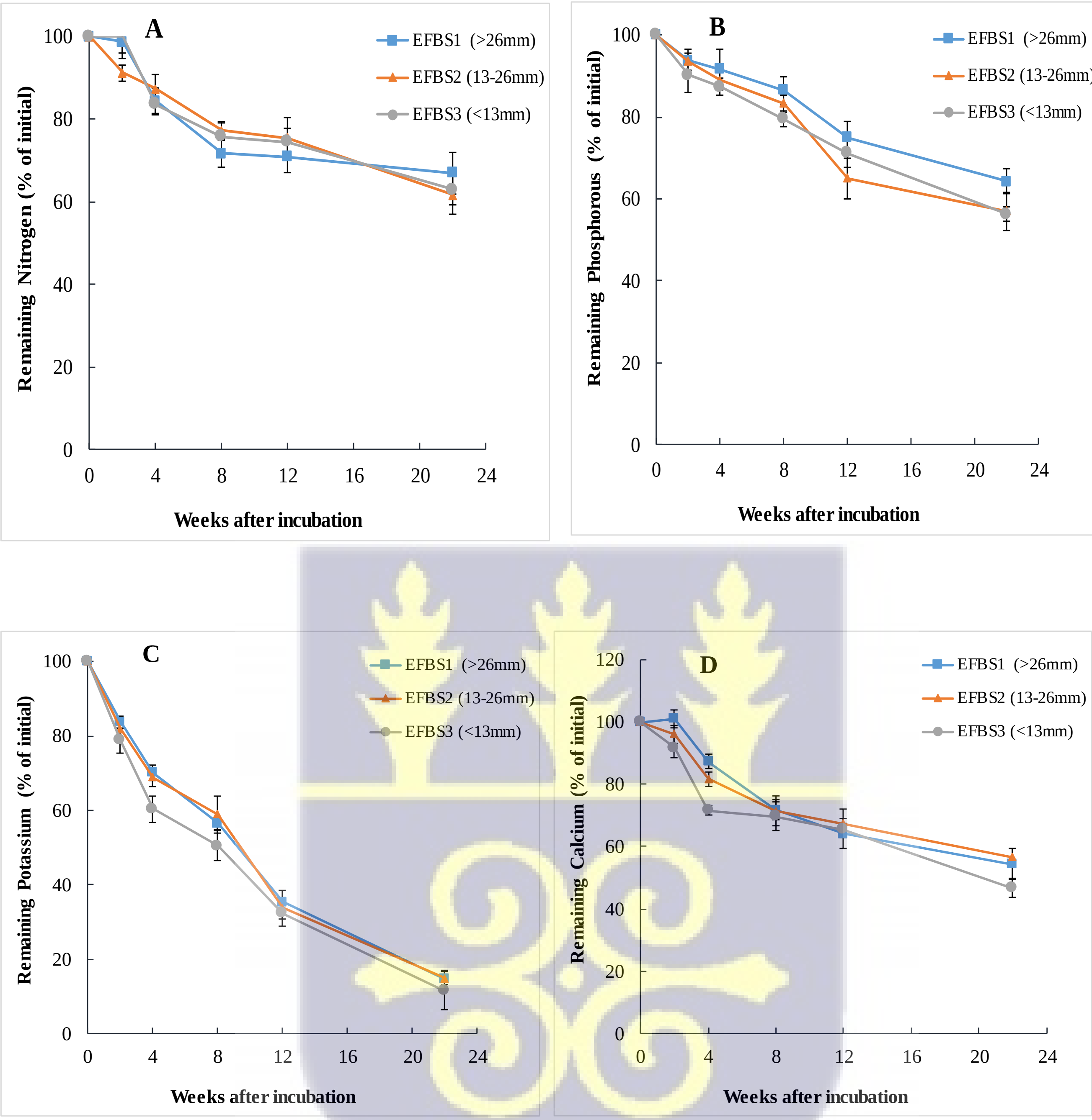

Figure 4. 20 Changes in the residual nitrogen (A), phosphorous (B), potassium (C) and calcium (D) as affected by empty fruit bunches particle sizes during the mineralization period

4.8.2.2.2 Cocoa pod husks

Overall, for all particle sizes of CPH, the nutrients were released in the order K> Ca > P = N at different rates. The changes in the remaining amount of nutrients of EFB as affected by particle size is shown in Figure 4.21. Nitrogen mineralization can be described into 2 main phases; the first phase (up to 8 weeks). Nitrogen mineralization was faster in CPHS1 and CPHS2 than in EFBS3, especially in the first 2 weeks of incubation. The situation was reversed from week 12 until the end of the experiment (Fig.4.21). The percent N remaining after 2 weeks were 79.8%, 79.4% and 100.2% in the order of reducing particle size while at the end of incubation, the percent N remaining were 63.9%, 63.6% and 55.6% in the order of reducing particle sizes.

There was no significant difference in Phosphorus mineralization among the particle sizes except at the end of incubation (week 22) where P released from CPHS3 was significantly higher than CPHS1 and CPHS2. The percent P remaining in order of reducing particle sizes were 66.1%, 62.1% and 54.8% of the initial content.

Throughout the incubation period, Potassium was released slowly in CPHS3 as compared to CPHS1 and CPHS2. However, this difference was statistically significant at week 12 only. Throughout the incubation period, the smaller the particle size, the faster the calcium mineralization but statistically significant only at week 8 and 12 where CPHS3 released significantly higher Ca than CPHS1 and CPHS2.

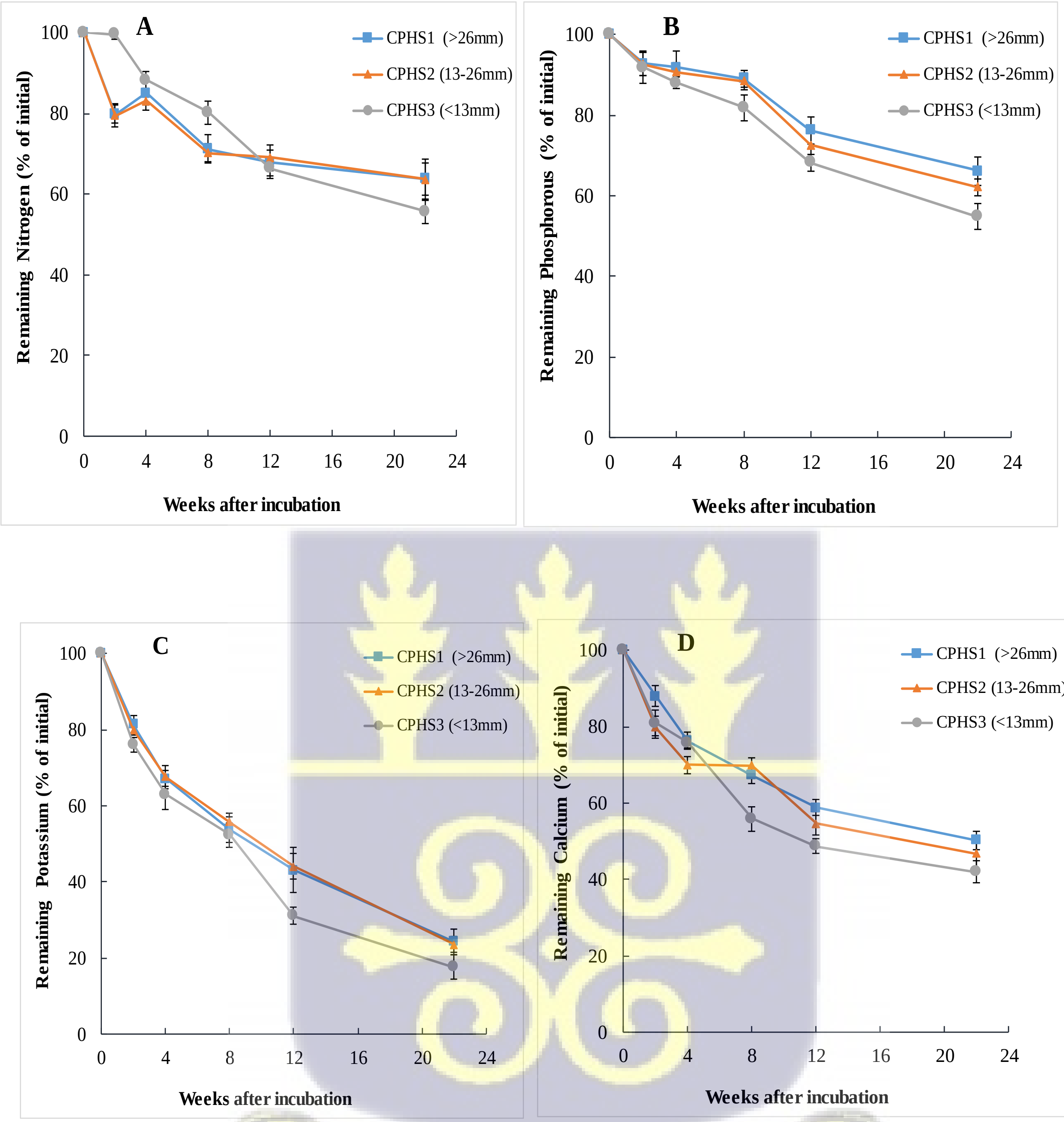

Figure 4. 21 Changes in the residual nitrogen (A), phosphorous (B), potassium (C) and calcium (D) as affected by cocoa pod husks particle sizes during the mineralization period

4.9 Effect of biochar amendment to poultry droppings on CO_2 emission

4.9.1 Cumulative carbon dioxide emissions

The addition of biochar to poultry droppings resulted in a highly significant reduction ($p<0.001$) of carbon dioxide emissions (Fig.4.22). Biochar addition resulted in more than 30% reduction of CO_2 emissions. The effectiveness of biochar in CO_2 emission reduction was more prominent at pH6 than pH4 and pH8. At 5% rate of RHB applied; biochar at pH6 was able to reduce 47.25% while biochar at pH8 reduced 34.32%.

The rate of biochar applied (5% and 10%) didn't show any significant difference on carbon dioxide emission.

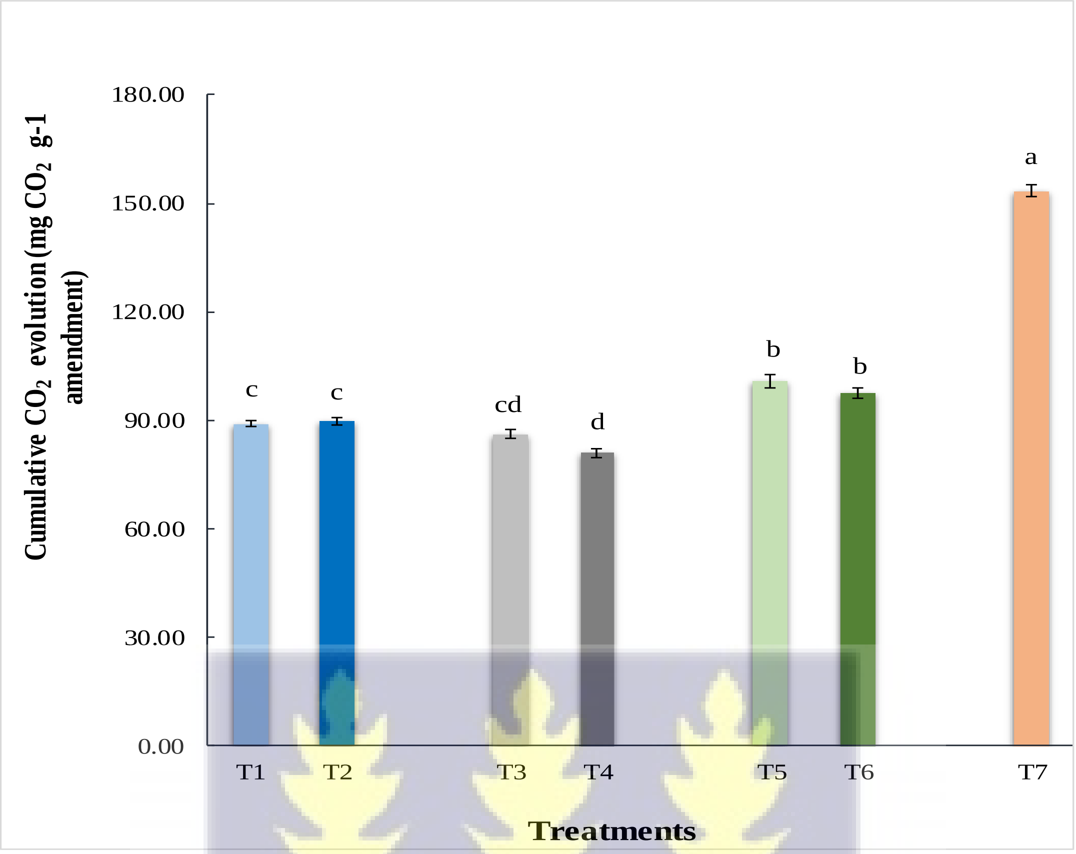

Figure 4. 22 Cumulative carbon dioxide emission as affected by biochar addition to poultry droppings. Means with the same letter are not significantly different from each other ($p>0.05$). Vertical bars indicate ± standard error of the mean of the observed values. T1: PD + (5% RHB, pH4); T2: PD + (10% RHB, pH4); T3: PD + (5% RHB, pH6); T4: PD + (10% RHB, pH6); T5: PD + (5% RHB, pH8); T6: PD + (10% RHB, pH8) and T7: 100 % PD. PD: poultry droppings and RHB: Rice husk biochar.

4.9.2 Dynamics of carbon dioxide emissions

As illustrated in Figure 4.23; carbon dioxide built up were initially high for all treatments and declined considerably thereafter. The highest CO_2 emission recorded was at 6th day for all treatments. Poultry droppings alone emitted significantly higher CO_2 throughout the incubation period.

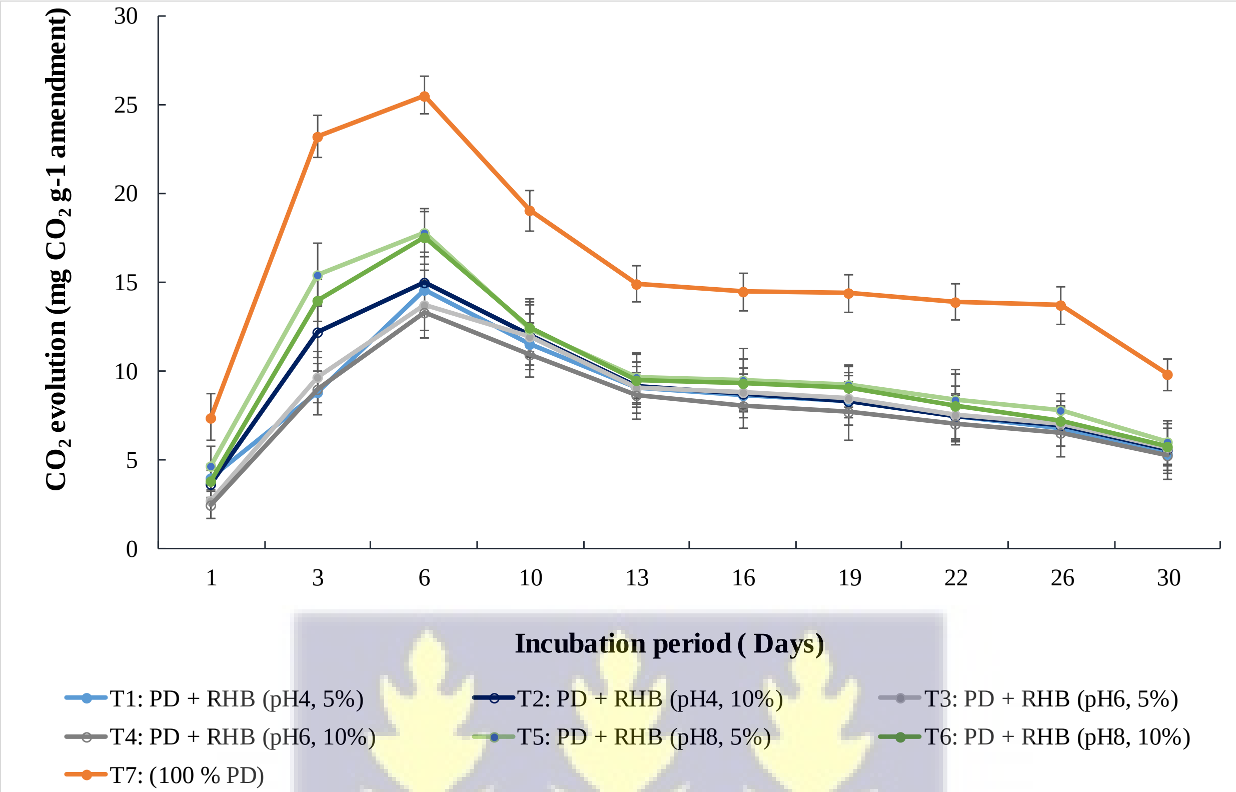

Figure 4. 23 Changes in carbon dioxide emission as affected by biochar addition to poultry droppings during the incubation period. Vertical bars indicate ± standard error of the mean of the observed values.

4.10 Effect of biochar amendment to poultry droppings on NH_3 emission

4.10.1 Cumulative ammonia emissions

The addition of biochar to poultry droppings resulted in a highly significant reduction ($p<0.001$) of ammonia emission (Fig.4.24). Biochar was effective in reducing more than 20% of NH_3 emitted by poultry droppings alone. Biochar was most effective at pH6 and less effective at pH8. Biochar at pH6 reduced 36.70% while biochar at pH8 reduced 21.86%.

Cumulatively, no significance difference was observed between 5% and 10% rate of biochar applied on ammonia emission, except biochar at pH4 where 10% rate reduced significantly ammonia emission than 5% rate.

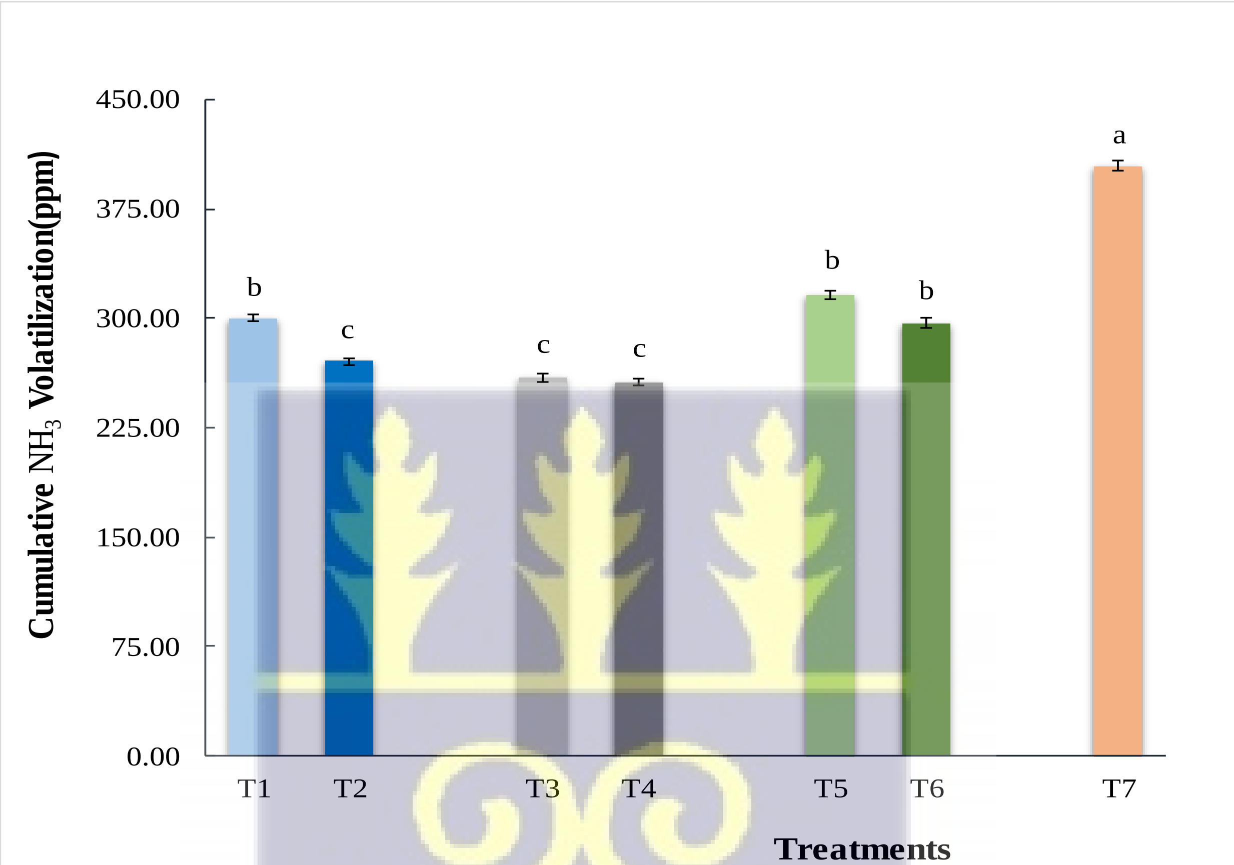

Figure 4. 24 Cumulative ammonia as affected by biochar addition to poultry droppings. Means with the same letter are not significantly different from each other ($p>0.05$). Vertical bars indicate ± standard error of the mean of the observed values. T1: PD + (5% RHB, pH4); T2: PD + (10% RHB, pH4); T3: PD + (5% RHB, pH6); T4: PD + (10% RHB, pH6); T5: PD + (5% RHB, pH8); T6: PD + (10% RHB, pH8) and T7: 100 % PD. PD = poultry droppings; RHB: Rice husk biochar.

4.10.2 Dynamics of ammonia emissions

There was a general increase of ammonia emission in the first five days after incubation for all treatments and declined thereafter. There was no significant difference in ammonia emission among all treatments at early stage of incubation. From 5th day, addition of biochar to poultry droppings reduced ammonia emissions in general (Fig.4.25). From day 5th day to 15th day, there was no significant difference in ammonia emitted by poultry droppings alone as compared to treatments with biochar addition at pH4 and pH8, whilst treatments with biochar addition at pH6 emitted significantly lower ammonia than poultry droppings alone. From 15th day onwards, poultry droppings alone emitted significantly higher ammonia than all other treatments.

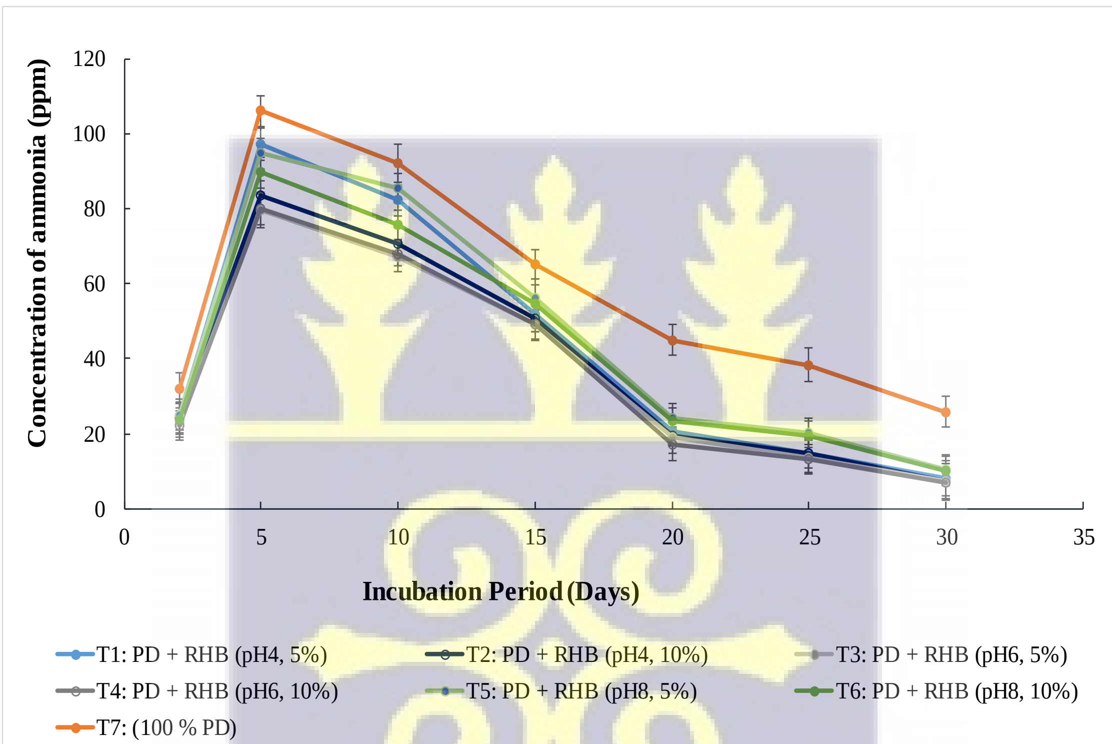

Figure 4. 25 Changes in ammonia emissions as affected by biochar amendment to poultry droppings during the incubation period. Vertical bars indicate ± standard error of the mean of the observed values.

4.11 Effect of biochar amendment to poultry droppings on nutrient release

Nutrients released as percent of initial after one-month incubation are presented in Table 4.7. Irrespective of biochar pH and rates, addition of biochar to poultry droppings generally influenced the release of nutrients, but with some exceptions. Nitrogen, phosphorus and potassium released from poultry droppings alone were significantly higher ($p<0.05$) than most of the treatments with poultry droppings mixed with biochar. Percent N released from poultry droppings alone was 32% and 41.1% for nitrogen and phosphorus respectively while for these other treatments with biochar addition, N and P released varied from 12.6-22.6% for nitrogen and 28.4-31.0% for phosphorus respectively. There was no significant difference ($p>0.05$) of calcium released among all treatments.

Overall, there was little influence of biochar pH and rate of application on nutrients release. There was no significant difference among different biochar pH and rates treatments in phosphorus, potassium and calcium release. Biochar at pH8 released significantly higher N as compared to other pH. However, this significance was observed only where biochar was applied as 10% rate. The rate of biochar affected nitrogen release, except for the biochar at pH4. The higher the biochar rate added to poultry droppings, the lower the percent of nutrients released.

Table 4. 7 Nutrient released over 30days of incubation of poultry droppings with biochar at different pH and rates

Treatments	Initial (%)	N (%)	P (%)	K (%)	Ca^{2+}(%)
	Nutrients amount released over incubation period (% of initial)				
T1: PD + (5% RHB,pH4)	100	17.5^{cd}	30.8^{b}	55.5^{ab}	26.1^{a}
T2: PD + (10% RHB, pH4)	100	13.3^{d}	28.4^{b}	55.1^{ab}	22.3^{a}
T3: PD + (5% RHB, pH6)	100	22.6^{bc}	31.8^{ab}	52.5^{b}	22.6^{a}
T4: PD + (10% RHB, pH6)	100	12.6^{d}	28.4^{b}	51.5^{b}	20.3^{a}
T5: PD + (5% RHB, pH8)	100	19.4^{bcd}	31.9^{ab}	56.9^{ab}	28.5^{a}
T6: PD + (10% RHB, pH8)	100	26.4^{ab}	31.0^{b}	52.3^{b}	21.7^{a}
T7 : 100 % PD	100	32.0^{a}	41.1^{a}	64.0^{a}	23.7^{a}

The values followed by different letters within the same column are significantly different among treatments ($p<0.05$).

CHAPTER FIVE

DISCUSSION

The agricultural sector plays a vital role in human and economic development and the sector keeps on increasing due to the increase in human population. The agricultural activities generate large quantities of wastes which can cause environmental pollution and threaten human health. The practice of managing agricultural wastes sustainably is low especially in developing countries. This research provided evidence for increased practice of sustainable use of agricultural wastes. Many researchers have engaged in research on issues related to sustainable management of agricultural organic wastes, especially by considering the recycling of the wastes in the soil. This work contributed to the matter. This section discusses the findings of this study in line with the existing literature on the under bring matter.

5.1 Assessment of major agricultural wastes generated within the study area and their management practices/uses by farmers

In the Kwaebibirem District, the cultivation of food and plantation crops and their processing generate high amounts of agricultural and agro-industrial residues. Oil palm, cocoa and citrus are the major traditional cash crops cultivated. The major crop residues generated were cocoa pod husks, empty fruit bunches and other waste produced by palm oil mills after the processing of fresh fruit bunches, rice husks and straws and corn stalks. This is in agreement with the findings of (Adamtey, 2005) who evaluated the agricultural and agro-industrial residues generated prior to composting within the Kwaebibirem district.

The majority of animal wastes generated in the communities are poultry and goat manure followed by sheep, cattle and pig manure. The poultry manure is produced in large quantities because poultry is the dominant animal reared in the district (KDA, 2016). Sixty-seven percent of the farmers responded that the wastes generated from agricultural and agro-industrial activities especially those produced by palm oil mills pose problems in the community. The problems mentioned are the pollution of rivers and streams, the mosquitoes' prevalence due to the wastes and the bad odor of the oil mills wastes for homes that are very close to the palm oil mills.

This study revealed that apart from few farmers who manage wastes appropriately, the practices applied by the majority of the farmers are the indiscriminate dumping of the wastes and incineration. The indiscriminate disposal or improper handling of organic agricultural wastes implicate the environment and human health as well as contributing to climate change which in turn impede food production (Adejumo & Adebiyi, 2020).

Open burning of organic agricultural wastes can cause air pollution such as haze, smoke containing carbon dioxide which accelerates climate change. Burning also release particulate matter which cause respiratory problems mainly in Asthma patients and children (Zainol *et al*., 2014).

More ecological friendly management options of agricultural wastes such as composting the wastes (Chamhuri, 2005) should be evaluated, since the raw materials are available in the community.

5.2 Assessment of farmer's knowledge and perception on sustainable management of agricultural wastes

Crop residues and animal wastes have a potential value, but the improper utilization of these organic wastes can cause environmental problems such as air pollution due to greenhouse gas emissions, underground and surface water pollution due to nutrient leaching which further affect the human health (Liu *et a*l., 2020).

This study assessed the farmer's knowledge and perception on the sustainable management of these organic agricultural wastes and found that about a half of the farmers who participated in the survey don't know the potential use of organic agricultural wastes generated in their communities. Some answered to have no idea on what they can use the wastes whilst others consider dumping the wastes to landfill, burning the wastes and burying the waste as appropriate approaches of managing the organic agricultural wastes.

The farmers who know the potential of the agricultural wastes stated the use of the wastes in soil fertility improvement through composting, biochar, incorporation or as mulch of wastes on their crop farms could be beneficial to them. Some studies have demonstrated that organic agricultural wastes can potentially be used in soil fertility improvement through composting (Kayode *et al*., 2018; Paul, 2014) or biochar production (Jiang, 2019; Yuan *et al*., 2018).

In addition to improving soil fertility, mulching the wastes as a potential practice of managing the organic agricultural wastes (Zainol *et al*., 2014) retains soil moisture through reduction in evapotranspiration, suppressing weeds growth, improving soil ecology and reducing soil erosion (Rosenani *et al*., 2016; Ibrahim *et al*., 2020).

Few of the farmers mentioned the use of crop residues in manufacturing bio fertilizers which is a sustainable way of managing organic agricultural wastes (Foereid, 2019).

5.3. Assessment of farmer's knowledge on the environmental challenges of using fertilizers

The study observed about 48% of the respondents who were aware of the environmental challenges caused by the continuous use of inorganic fertilizers. The respondents mentioned water pollution, air pollution, soil compaction and threatening human health as some of the challenges confronting the farmers.

It is well known that regular use of inorganic fertilizers results in nutrient imbalances and environmental concerns, consequently weakening the soil productivity sustenance (Dey *et al*., 2019). Overall, farmers seemed to have little knowledge on the environmental challenges of using organic fertilizers. However, depending on the type of organic agricultural waste (Sacco, Pelissetti, Dinuccio, & Rostami, 2012) used, the way the waste was applied as well as environmental conditions (Sommer & Hutchings, 2001); organic fertilizers can also be associated with some environmental threats. Animal manure accounts for significant percentages of anthropogenic greenhouse gases emission (Paul, 2014).

5.4 Characterization of organic residues (EFB, CPH, RH and PD) used in the experiments

The EFB recorded N, P, K, Ca and Mg contents of 1.19, 0.22, 2.18, 0.38 and 1.06% respectively. The findings are in agreement with the previous studies. According to Rosenani *et al*. (2016); EFB contains 0.76 - 0.96% of N, 0.14 - 0.18% of P, 1.21- 3.2% of K, 0.36 - 0.60% of Ca and 0.220.51% of Mg. The results of the chemical parameters studied fall within the ranges reported by Rosenani except for nitrogen and phosphorous. This difference could be attributed to the kind of processing used in producing EFB from palm fruit bunches, especially difference in the temperature used in processing industry. However, nitrogen content obtained from this study is in agreement of that indicated by (Anyaoha *et al*. (2018) who reported a range of 0.24 -1.65% of nitrogen. EFB recorded cellulose and lignin content of 43.06 and 30.25 percent respectively. These falls in the accepted ranges of 13.75-59.70% cellulose and 7.79-30.45% lignin.

The CPH recorded N, P, K, Ca, Mg, cellulose and lignin contents of 1.55, 0.17, 3.28, 0.43, 0.97, 26.05 and 20.97% respectively. The findings are in agreement with those reported by (Fidelis & Rao (2017) who reported 1.56% of nitrogen and 0.75% of Magnesium. The findings also fall within the range stated by (Lu et al., 2018) who reported 0.19% of P CPH, 2.8-3.8% of K, 0.25-0.46% of Ca, 19.7-26.1% of cellulose and 14-28% of lignin.

Both EFB and CPH contain high organic carbon and low nitrogen, phosphorous and calcium with EFB having the least nitrogen and calcium. This is perhaps due to the high temperature and pressure applied to fruit bunches in palm oil processing which could have denatured these nutrients (Moradi *et al*., 2014). Nitrogen is essential nutrient for the growth of microorganisms, therefore has a notable effect on residues degradation by microorganisms.

Rice husk biochar (RHB) was rich in carbon but had very low nitrogen and phosphorous contents which are attributed to the high temperature that is used in the pyrolysis process (Prakongkep *et al*., 2013). Hence, biochar should be used in combination with other soil amendment which contain notable macronutrients such as poultry droppings. The RHB had the alkaline pH which makes it to be suitable for use as soil amendment particularly in acidic soils (Munongo *et al*., 2017).

Generally, the organic residues contain plant nutrients which guarantee them to be used as soil amendments. However, their high carbon-nitrogen ratio and lignocellulose components makes them to decompose slowly.

5.5 Effect of organic residues type and particle size on carbon dioxide emission

Application of organic residues in the soil undergo biological degradation in which carbon is used by microbes in respiration, which releases carbon dioxide (Chen *et al*., 2015), a greenhouse gas.

The findings of this study showed that the physical and biochemical constitution of crop residue affect the microbial respiration.

In this study, for both EFB and CPH, initially, there were acceleration in C mineralization with decreasing particle size. It is asserted that during the lag phase, the delay is necessary for the colonization and induction of enzymes production as well as the moistening of the residue (Bremer *et al*., 1991). Smaller particle sizes treatments favored those factors because they were present in larger number which facilitated a greater and more homogeneous contact with the soil (Angers & Recous, 1997; Yan *et al*., 2012).

However, for EFB, carbon dioxide peaked with the smallness of particle size until the 60^{th} day and reversed at later stage (after 60 days) whilst for CPH; carbon dioxide peaked with the smallness of particle size from the 1^{st} day to 20^{th} day, and from 72^{th} day until the end of the experiment. In the middle stages the rate of carbon dioxide emission was similar for the three CPH particle sizes.

The findings of this study showed that reducing the particle size of crop residue influenced the microbial respiration. Particle size determines the available surface area for microbial colonization and influences the exchange of nutrients, water and oxygen between soil and the substrate (Iqbal *et al*., 2010; Bending & Turner, 1996; Swift, 1979). Furthermore, particle size may control the contact of the organic residue with soil particles, especially clay and silt, which can limit the access of microbes to the organic residue (Hassink, 1997; Bending & Turner, 1996). Similar findings were presented by Bending & Turner (1999) and Angers & Recous (1997) who observed the faster carbon mineralization for smaller size of Brussels Sprout shoots and maize straws. However, they observed reverse effect on potato shoot and young rye residues, which was explained by the high nitrogen contents of the later residues.

Other studies reported that the particle size didn't affect the microbial respiration (Jensen, 1994; Singh, Rengel, & Bowden, 2004), which could be attributed to the difference in the texture of soils used in the experiments as well as environmental factors. Additionally, the mode of organic residue application might also be a factor since I applied the organic residue on the surface of the soil in this study unlike incorporating the residues into the soil by the other studies.

5.6 Effect of organic residue type and particle size on decomposition and nutrient release

5.6.1 Effect of organic residue type and particle size on decomposition

Mass loss followed the single exponential decrease. The rate of mass loss was initially high but decreased in the later stages. These observations confirm earlier findings by Moradi *et al*. (2014) and Rosenani & Hoe (1996). This is attributed to the presence of different kinds of materials such as amino acids, soluble sugars and cellulose which undergo faster decomposition than more recalcitrant materials like lignin (Rosenani & Hoe, 1996; Swift, 1981) and the amount of residue that the microbes are acting on.

The decomposition of EFB and CPH were significantly greater for smaller particle sizes throughout the incubation period. This is due to the fact that smaller particles present larger surface area which facilitated a greater and more homogeneous contact with the microbes (Bremer *et al*., 1991; Sims & Frederick, 1970). The mass loss of CPH was faster than that of EFB. This difference could be due to the differences in the C: N ratio and lignin content of CPH (Berg & Laskowskil, 2006).

The results showed that during the early decomposition up to 4 weeks, difference in particle sizes did not affect decomposition rate. This results confirms earlier reports by Akhtar Iqbal, Garnier, & Lashermes (2013) who reported equivalent rate of decomposition of high C: N residues in early stages of the decomposition. On the other hands, higher rate of decomposition from the finer residues in the early stage of decomposition have been reported (Angers & Recous, 1997). The difference in the findings might be attributed to difference in the morphology and tissue organization of the crop residues (Iqbal *et al*., 2013).

5.6.2 Effect of organic residue type and particle size on nutrient release

The nutrients were released in the order K > Ca > P = N at different rates for both crop residues. Similar trend in nutrient release was reported by Rosenani *et al*. (2016). According to Khalid (2000), the mineralization of nutrients depends on whether they are in the component as with structural materials (Ca), with the cell lumen (N and P) or exists in ionic form in the vacuole of the cells (K).

The K released from EFB and CPH reflected the initial K content in each of crop residue. Cocoa pod husks with higher initial K content released 82.4, 76.5 and 75.6% for CPHS3, CPHS2 and CPHS1 respectively, whilst EFB which is relatively poor in K released 88.5, 85.2 and 85.4% for EFBS3, EFBS2 and EFBS1 over the same period of 22 weeks. The rapid loss of K is attributed to the fact that it exists as a sulfate salt in the tissues of crop residues which enhanced K to easily leached out (Moradi et al., 2014). Thus K release depends highly on the moisture during the decomposition (Aita, 2003; Cavalli *et al*., 2017) rather than the residue quality or microbial activity (Reshi &Tyub, 2003).

Calcium followed K, probably due to the degradation of hemicellulose and cellulose which releases calcium even though calcium usually exists as calcium pectin or pectates, cell walls structural components (Bockheim & Jepsen, 1991).

The slow release of nitrogen and phosphorous could probably be due to longer retention time which resulted in immobilization (Aita, 2003; Hougni *et al*., 2021), this indicates that organic matter was decomposed and absorbed by microbes.

There were no significant differences in the N and P release in EFB and CPH, in spite of the differences in their initial characteristics, particularly C: N ratio, lignin and polyphenol contents. This could be due to the distinct distribution of these nutrients in various components of plants (Grzyb et al., 2020). Phosphorus was lost rapidly in the first 2 weeks, indicating the removal of soluble P by irrigation water (Eldin & Ibrahim, 2006).

Earlier stages of mineralization showed that more mineral P was released from smaller than bigger particle sizes, which could be attributed to the enhanced microbial activity as a result of the increased available surface area for colonization (Bending & Turner, 1999).

5.7 Effect of biochar amendment to poultry droppings on carbon dioxide emission

Application of biochar to poultry droppings reduced significantly the net amount of carbon dioxide emission. Similar results have been reported in earlier studies. Abagandura *et al*. (2019) reported a reduction of carbon dioxide flux when chicken manure was mixed with biochar. On the other hand, Jia *et al*. (2016) reported that the addition of biochar to poultry droppings increased carbon dioxide emission. This difference could probably due to the difference in biochar properties, especially higher pH (10.45) of the biochar he used. Furthermore, it has been reported that different properties of biochar affects the quantity and course of carbon dioxide emission (Yuan *et al.*, 2018). The biochar with high porosity increases the oxygen supply, which benefits microorganisms that degrade organic matter to produce carbon dioxide. Biochar has been reported to affect the structure of the microbial community (Abujabhah *et al.*, 2016; Gao *et al.*, 2017).

Carbon dioxide built up were initially high for all treatments but declined over time. Similar trend was also reported the higher release of carbon dioxide in the first week (Miyittah & Inubushi, 2011). This can be explained by the faster degradation of the organic carbon by microbes and the reduction of the quantity of the resource.

Variations in pH of the biochar showed little effect on carbon dioxide emission, hence, it can be stated that neutral to acidic biochar can be effective in reducing carbon dioxide emissions.

5.8 Effect of biochar application to poultry droppings on ammonia emission

The addition of biochar reduced the ammonia emissions, confirming earlier reports (Rong *et al.*, 2019; Esfandbod *et al.*, 2017; Mandal *et al.*, 2016). Biochar is capable of affecting the bacteria diversity structure as well as the capacity of adsorbing the water-soluble ammonium ion (NH_4^+) and ammonia gas possibly due to its pore structure (Liu *et al.*, 2017) and functional groups that contain oxygen like Carboxyl-C=O, phenolic-OH and nitrogen-hydrogen stretching groups on the biochar surface.

Biochar at pH8 was less effective in reducing ammonia emission as compared to pH4 and pH6. According to Janczak *et al*. (2017), pH might have shifted the ammonium-ammonia equilibrium to ammonia. Schomberg (2012) reported that application of biochar with high pH to chicken manure composting increased NH_3 volatilization compared to the control. This would be explained by the report that at high pH, ammonification process accelerates thereby increasing NH_3

volatilization. Esfandbod *et al*. (2017) also suggested that the less effectiveness of alkaline biochar in reducing ammonia emissions results from the strong acid-base reaction which drive ammonia emissions.

Ammonia emission was high in the first five days after incubation and declined thereafter. The high ammonia loss at early days of incubation could be ascribed to the ammonification of labile nitrogen while the moderate ammonia evolution was possibly due to the mineralization of more recalcitrant nitrogen fractions (Janczak *et al*., 2017).

In general, the rates of biochar applied didn't affect significantly ammonia emission in general. These results confirm earlier studies that biochar application rate of 4% had significant effect in reducing ammonia emission (López-cano *et al*., 2016).

There seem to be an effect of pH and rate of biochar application, further investigations are needed to determine how these parameters affect microbial community responsible for ammonification.

5.9 Effect of biochar amendment to poultry droppings on nutrient release

Study results indicated that addition of biochar to poultry droppings generally influenced the release of nutrients. Application of biochar to poultry droppings reduced nutrients release rate. A similar effect was confirmed by Adekiya *et al* (2019) who observed that biochar reduced nutrient release rate of poultry manure due to the capacity of biochar to retain nutrients. The large surface area and carboxylate groups on biochar are the main source of the biochar high nutrients retention capacity (Purakayastha *et al*., 2015). This study showed that nitrogen, phosphorus and potassium released from poultry droppings alone were significantly higher ($p<0.05$) than most of the treatments with poultry droppings mixed with biochar. This is attributed to the capacity of biochar to adsorb dissolved soluble nutrients like nitrates, ammonium phosphates as well as other ionic solutes (Lehman *et al*., 2002; Yao *et al*., 2012). Biochar at pH8 released significantly higher N and OC as compared to other lower pH. Similar results were reported by Qi *et al*. (2017) suggesting that acidic biochar might influences microbial activity responsible for N mineralization. The lower percent of and N release from higher biochar rates might due to the decrease in the microbial activity due to recalcitrant nature of biochar, hence the degradability of the substance dictates the kinds of microbes to degrade (Iren & Ediene, 2021; Glaser, 2016). Wang *et al*. (2017) indicated that the capacity to adsorb ammonium nitrogen correlated positively with the amount of biochar used. Biochar is capable of releasing nutrients slowly as a result of its chemically stable structure (Figueredo *et al*., 2017).

Wastes from agricultural activities are associated with serious environmental challenges if mismanaged. Current management practices of major agricultural wastes are poor. These wastes contain plant nutrients, hence the agricultural wastes play a very important role in agriculture because they can be used as an environment-friendly waste management strategy and as means of improving SOM.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The objective of the study was to find out the management practices of major agricultural wastes and evaluate their impact on decomposition and mineralization in the Kwaebibirem district. Even though considerable amount of crop nutrients is removed in the harvests/yield, plant residues that remains after processing contained sizable amount of plant nutrients, therefore the management of these crop residues has relevant implications on soil fertility management, agricultural production and environmental protection as well. In the Kwaebibirem district, where about 70.8% households are engaged in agriculture. This is very important as resource in soil fertility since it is locally available and inexpensive, reducing the dependence on inorganic fertilizers.

i. The findings of this study shows that the major agricultural wastes generated in the district are crop residues and animal wastes. The most crop residues generated are cocoa pod husks; various wastes from palm fruits namely- empty fruit bunches, palm kernels and palm oil mill effluents (POME); rice husks and straws and corn stalks. Animal wastes generated are predominantly poultry manure. Goat, sheep, cattle and pig manure are also present. According to the farmers especially those whose households are in close proximity with palm oil mills asserted that the wastes were problematic.

ii. The study findings indicated that the farmers have inadequate knowledge on the sustainable management of agricultural wastes. Also, most of the farmers perceive weakly in animal manure use in soil fertility improvement, Hence, the necessity of education intensification in addressing the issue of agricultural wastes management.

iii. The study showed that weight loss in both EFB and CPH followed a single exponential model. Particle size of both organic residues affected their decomposition and mineralization patterns and carbon dioxide emission as well.

iv. Results obtained from incubation studies showed that irrespective of biochar rates and pH; application of biochar to poultry droppings resulted in a highly significant reduction ($p<0.001$) of carbon dioxide and ammonia emissions. Biochar was effective in reducing more than 30% of carbon dioxide and 20% of ammonia emissions compared to poultry droppings alone. Biochar at pH6 was most effective in reducing CO_2 and NH_3 emissions.

v. This study's findings revealed that addition of biochar to poultry droppings generally influenced the release of nutrients although there were some exceptions. Biochar with lower pH showed to retain nutrients more than biochar with higher pH.

6.2 RECOMMENDATIONS

In light of the study findings and conclusions, the following recommendations were made:

i. The study recommends education and trainings of farmers on the impact of agro-industrial waste to the environment, the possible and affordable environmentally friendly management practices that can be used in managing the wastes to encounter the problems caused by inappropriate management or disposal of these wastes such as composting.

ii. The practices related to soil fertility are highly encouraged since the wastes have shown to contain plant nutrients and it is confirmed that the climate smart agriculture encourages the recycling of agricultural waste in soil. Farmers should also receive education on the disadvantages of using inorganic fertilizers through agricultural extension officers. Soil fertility oriented knowledge is better than yield oriented knowledge.

iii. Extension services should intensify education and trainings on the use of available local organic resources for soil fertility improvement. farmer field schools and the Radio campaigns are suggested. For the soil fertility conservation and enough organic fertilizer production, farmers should efficiently manage the crop residues and animal wastes produced.

iv. Both EFB and CPH are suited for soil organic matter build-up and chopping the residues in small particle sizes is advised for short term fertility purpose. CPH may be an alternative to provide nutrients to the soil as a manure, especially if K is highly needed in the soil**.**

This study expected a difference in the nitrogen and carbon mineralization of EFB and CPH as a result of different amount of nitrogen and carbon, However, the results showed insignificant difference. This might be due to the distinct distribution of these nutrients, indicating that the distribution of carbon and nitrogen should also be considered rather than their total contents alone.

v. The results suggest the consideration of both physical and chemical quality in residue decomposition and mineralization.

vi. Based on the results of mixing biochar with poultry droppings, biochar should be added to poultry droppings to retain nutrients, reduce carbon dioxide and ammonia gases emissions as a waste management strategy to reduce as well. Biochar addition to poultry droppings could conserve ammonium from volatilization and therefore be available for use in plant nutrition. Rice husks are mostly far from farmers, if carbonized, the material product is easier to transport and help in land sustenance with low pollutant gas emissions.

vii. This study focused on the decomposition, nutrient release and gases evolution of the decomposing amendments. Future studies should concentrate on the soil nutrients changes and other soil properties as well. Microbial characterization is also needed for a deep understanding and interpretation of the results.

viii. Field experiments are required to evaluate the validity of this study's findings in the natural environments.

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APPENDICES

Appendix 1: SAMPLE FARMER QUESTIONNAIRE

Students at the University of Ghana are obliged to tackle social and environmental issues related to their study as part of their partial fulfillment of the requirements for the degree of M. Phil. Environmental Science. As a consequence, the following questionnaire has been created to assist in the gathering of data for the above-mentioned research topic to help identify the major agricultural wastes generated within the Kwaebibirem district, management practices used by farmers and to evaluate farmer's knowledge and perception on the sustainable management of agricultural waste. If you could assist with the completion of this questionnaire, it would be greatly appreciated. Responses will be kept strictly confidential and used for academic purposes only.

Community.......................................Location of farm....................................Date...............

Please tick [√] or write the correct answers where appropriate.

Section A: Sociodemographic Information of Farmers

1. **Gender** a) Male [ ] b) Female [ ]

2. **Age** a) Below 15yrs [ ] b)15-24yrs [ ] c)25-34yrs [ ] d)35-44yrs [ ] e)45yrs & above[ ]

3. **Level of education** a) None[ ] b)Basic[ ] c)Secondary[ ] d)Tertiary[ ] e)Other (specify).................

4. **How long have you been farming (crops)**? ……………………………………

5. **How do you obtain the land for cultivation?** a) Family land [ ] b) Freehold/leaseland [ ] c) Rents the land [ ] d) Share cropping [ ] e) Other (please specify)……......................

6. **What is the most important crop that you are growing**? a) Cocoa[ ] b)Oil palm[ ] c)Cocoyam [ ] d)Maize[ ] e)Rice [ ] f) Plantain [ ] g) Other (Please specify)……………

7. **What is your total land size?**...................... (acre, Hec, poles, rope)

8. **What type of farming methods do you employ?** a) Traditional [ ] b) Mechanized [ ] c) Semi mechanized [ ]

9. **Are you into subsistence or commercial farming?** a) Subsistence [ ] b) Commercial [ ]

10. **Do you have any other occupation(s) beside farming?** Yes [ ] No [ ]

11. **If Yes, kindly state your other occupation**…………………………

Section B: Farmer's Knowledge on the use of organic and inorganic amendments in soil fertility management

12. **Do you use soil amendment/fertilizers in farming?** Ye [ ] No[ ] **if No, go to Qn28**

13. **If yes, which soil amendment do you use?** a) Inorganic [ ] b) organic [ ] c)both[ ]

14. **If both, which one do you prefer?** a) Inorganic [ ] b) organic [ ]

15. **If organic in (Qn. 13) which one of these do you use?** a) animal manure [ ] b)crop residues [ ] c) Compost [ ] d) Others (please specify)………

16. **If inorganic in (Qn.13), Which one of these do you use?** a) NPK [ ] b) urea [ ] c) other (please specify):………..

17. **Why your choice in question (14/15/16)** a) less expensive [ ] b) readily available [ ] c) easy to use [ ] d) increases yield rapidly [ ] e) Others (please specify) ....…...............

18. How do you know the amount of amendment to apply? a) as much as I can [ ] b) No specific measurement [ ] c) depending on the level of the previous yield (experience) [ ] d) advise from extension agent[ ] e) radio/Tv/social media [ ] f)project/NGO [ ] g) others (please specify) ....

19. How do you apply the soil amendment? a) Incorporation [ ] b) Base placement [ ] c) mulch (surface application) [ ]

20.Briefly explain the reasons for your choice in (Qn 19)?...

21. Are you aware of the environmental challenges of using organic fertilizers (animal manures, compost, crop residues, etc) a) Yes [ ] b)No [ ]

22. If yes, mention these challenges ………………………………………………………………

……

23. Are you aware of the environmental challenges of using inorganic fertilizers (NPK, Urea, etc)? a) Yes [ ] b)No [ ]

24. If yes, mention these challenges ………………………………………………………………

……………………………………………………………………………………………………….

25. Do you think that organic fertilizers are better than inorganic fertilizers? a) Yes [ ] b)No [ ]

26. Which one do you use mostly? ……………………………………………………………

27. Kindly explain the reasons of your answer above..

28. Why don't you use soil amendment? ……………… ……………………………

Section C: Management practices of agricultural wastes by farmers

29. After harvesting, what do you do with crop residues left? a) Compost [ ] b) Reuse on farm [ ] c) Mulching [ ] d) Incineration [ ] e) Animal bedding [ ] c)livestock feed [ ] e) Others (please specify)………................

30. Briefly explain the reasons of your choice in question (29) ....….................

………………………………………………………………………………………………….

31. Do you rear animal in the farm or elsewhere? a) Yes [ ] b)No [ ]

32. If yes, which animal do you rear? a) cattle [ ] b)goats [ ] c)sheep [ ] d)poultry [ ] e) Other (please specify)………………………..

33. How do you store your animal manure before use or dispose from the farm?.................

………………………………………………………………………………………………..

34. What do you do with the wastes generated? a) Use as soil amendment [ ] b) Dump outside [ ] c) burying in the ground [ ] e)Others (please specify)………................

35. Briefly explain the reasons of your choice in question (34) …………………………..

Section D: Farmers Knowledge and Perception on sustainable management of agricultural wastes

36. What kinds of agricultural organic wastes do you know of? a) Crop residues [ ] b) Cow dung [ ] c) Poultry manure [ ] d) Pig manure [ ] e) Other (please specify)……………………

37. What are the major agricultural wastes generated in this farming community? mention at least four: 1…………………2……………….3……………………4………………….

38. Are the agricultural waste named above profitable for you? Yes [ ] b) No [ ]

39. If yes, explain briefly what do you do with the waste?...

……………………………………………………………………………………………

40. Do you know how these waste should be disposed to the environment? Yes [ ] b) No [ ]

41. In your opinion, how do you think the waste should be managed?..............................

……………………………………………………………………………………………

42. Do you know that using these agricultural wastes improves soil fertility? Yes [ ] b) No [ ]

43. Is agro-industrial waste a problem in the farm/community? a) yes, it is a major problem [ ] b) yes, it is only a minor problem [ ] c) No, it is not [ ]

44. Do you know the benefits of retaining crop residues (empty fruit bunches, cocoa pod husks, maize straw, rice husks, etc.) in the field after harvesting? Yes [ ] b) No [ ]

45. If Yes, How do you use the crop residues a) as obtained [ ] b) chop into smaller size [ ] c) other (please specify)……………………

46. Kindly mention these benefits in (Qn 44) ……………………………………………

…………………………………………………………………………………………….

47. Have you ever heard of biochar? a) Yes [ ] b)No [ ]

48. If Yes, Have you applied it before? a) Yes [ ] b)No [ ]   If No, go to question (53)

49. Why do you use biochar? a) Advice from the other farmers [ ] b) Briefings by agriculture officer [ ] c) Radio news [ ] d) printed media and/or electronic media [ ] e) Project/NGO[ ] f) Other (please specify)…………………………………

50.What kinds of changes did you noticed after using biochar? State your observations…

……………………………………………………………………………………

51. Did you come across any particular problem when using biochar? Yes [ ] b)No [ ]

52. If Yes, mention them………………………………………………………………

53. Why didn't you use biochar? a) Because it requires labor force to prepare [ ] b) Because it is time consuming [ ] c) Because of lack of training and technical advice [ ] d) other (specify)…..

54. Are you prepared to use biochar if the reasons given above is or are solved? Yes [ ] b)No [ ]

55. Which of these would you like? a) to receive education on the importance and use of biochar [ ] b) to receive training in biochar production [ ] c) to buy biochar from manufacturing sources

56. Kindly indicate your level of agreement with each of the statements below by checking (√) the appropriate boxes.

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Inappropriate use of agricultural wastes can cause environmental problems including the impairment of air quality due to greenhouse gas emissions and nutrient leaching					
2. Re-use of crop residues on farm reduces environmental and financial costs associated with waste disposal or recovery					
3.On-farm composting eliminates environmental and financial costs associated with transportation					
4. Biochar production reduces waste volume and eliminates other harmful residues					
5. Biochar improves soil health and combat climate change					
6. Re-using and recovering agricultural waste on farm is time consuming					
7. Re-using and recovering agricultural waste on farm improve soil fertility					
8. Re-using and recovering agricultural waste on farm have the potential to increase the yield					
9. To protect the environment, I pick-up, store and utilize or dispose of manure properly					

______Thank you for your co-operation and contributions! ________

Appendix 2: EXPONENTIAL FUNCTIONS OF REMAINING MASS AND NUTRIENTS

Table showing exponential functions of remaining mass and nutrients

Parameters	Treatments	Fitted models	Adjusted R^2	Half-life period in weeks ($t_{0.5}$)
Mass remaining	EFBS1	$98.840e^{-0.030t}$	0.93	23.10
	EFBS2	$95.168e^{-0.026t}$	0.92	26.65
	EFBS3	$93.087e^{-0.032t}$	0.92	21.65
	CPHS1	$91.032e^{-0.030t}$	0.91	23.10
	CPHS2	$87.514e^{-0.031t}$	0.89	22.35
	CPHS3	$87.408e^{-0.039t}$	0.88	17.76
Nitrogen	EFBS1	$94.341e^{-0.019t}$	0.78	36.47
	EFBS2	$95.864e^{-0.021t}$	0.97	33
	EFBS3	$96.831e^{-0.021t}$	0.90	33
	CPHS1	$88.832e^{-0.018t}$	0.76	38.5
	CPHS2	$88.145e^{-0.017t}$	0.75	40.7
	CPHS3	$100.320e^{-0.028t}$	0.97	24.75
Phosphorous	EFBS1	$99.037e^{-0.02t}$	0.98	34.65
	EFBS2	$98.640e^{-0.027t}$	0.95	25.66
	EFBS3	$97.126e^{-0.025}$	0.99	27.72
	CPHS1	$98.869e^{-0.019t}$	0.96	36.47
	CPHS2	$99.126e^{-0.022t}$	0.96	31.50
	CPHS3	$98.505e^{-0.027t}$	0.99	25.66
Potassium	EFBS1	$102.050e^{-0.087t}$	0.99	7.96
	EFBS2	$101.010^{-0.086t}$	0.99	8.06
	EFBS3	$97.827e^{-0.095t}$	0.99	7.29
	CPHS1	$91.929e^{-0.062t}$	0.99	11.18
	CPHS2	$92.801e^{-0.063}$	0.99	11
	CPHS3	$91.191e^{-0.078t}$	0.98	8.88

Calcium	EFBS1	$98.840e^{-0.030t}$	0.93	23.10
	EFBS2	$95.168e^{-0.026t}$	0.92	26.65
	EFBS3	$93.087e^{-0.032t}$	0.92	21.66
	CPHS1	$91.032e^{-0.030t}$	0.91	23.10
	CPHS2	$87.514e^{-0.031t}$	0.89	22.35
	CPHS3	$87.408e^{-0.039t}$	0.88	17.79
Organic carbon	EFBS1	$96.526e^{-0.025}$	0.97	27.72
	EFBS2	$98.924e^{-0.027t}$	0.98	25.66
	EFBS3	$91.888e^{-0.033t}$	0.95	21
	CPHS1	$93.795e^{-0.031t}$	0.97	22.35
	CPHS2	$93.053e^{-0.033t}$	0.97	21
	CPHS3	$90.956e^{-0.035t}$	0.95	13.86