COMPOSTING OF ORGANICALLY AMENDED/TREATED HARDWOOD AND SOFTWOOD SAWDUST

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DECLARATION

This thesis is the outcome of research work undertaken by Rita Takyi-Lartey in the Department of Nuclear Agriculture and Radiation Processing of School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Daniel Asare and Dr. Rose Boatin.

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DEDICATION

This work is dedicated foremost to the Lord God Almighty for his protection and guidance and to my grandfather Mr. Samuel Coffie, my loving and caring mother, Miss Georgina Coffie and sister Stella Takyi as well as my husband Mr. William Lartey for their support and prayers.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BNARI	Biotechnology and Nuclear Agriculture Research Institute
Cd	Cadmium
Cu	Copper
C:N	Carbon and Nitrogen ratio
CO_2	Carbon dioxide
CRB	Completely randomized block
CSIR	Council for Scientific and Industrial Research
EMBA	Eosin Methylene Blue Agar
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agricultural Organisation of the United Nations
FCC	Faecal Coliform Count
Fe	Iron
FTIR	Fourier Transform Infrared Spectroscopy
GAEC	Ghana Atomic Energy Commission
HCl	Hydrochloric acid
H_2O_2	Hydrogen peroxide
HSC	Hardwood sawdust compost
H_2SO_4	Sulphuric acid
K	Potassium
Mn	Manganese
MOFA	Ministry of Food and Agriculture

N	Nitrogen
NaOH	Sodium hydroxide
OLS	Ordinary Least Squares
P	Phosphorus
Pb	Lead
pH	Hydrogen ion concentration
SESRC	Soil and Environmental Sciences Research Centre
SSC	Softwood sawdust compost
TAMB	Total Aerobic Mesophilic Bacteria
TCC	Total Coliform Count
TVC	Total Viable Count
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNEP	United Nations Education Programme
VRBA	Violet Red Bile agar
Zn	Zinc

ABSTRACT

Sawdust is a major waste produced by the wood industry. Adding value to sawdust through composting is one of the surest means by which environmental pollution could be minimized. About 500 kg of softwood and hardwood sawdust were separately mixed with mucuna leaves and kitchen waste in the ratio of 3:1:1 on weight basis and heaped using effluent from abattoir to develop composts. Objectives of the study were to monitor changes in the physico-chemical properties, NH_4^+ – N, NO_3^- – N, C:N ratio, minerals N, K, P, microbial load and toxic elements in the composts during a 12 week period. Germination test was also done to evaluate the stability and maturity of the composts developed. Degradation of softwood sawdust compost (SSC) was better in the mesophilic phase while that of hardwood sawdust compost (HSC) occurred in the thermophilic phase. Thus, significantly higher amount of the organic material in SSC was decomposed during the period as compared to HSC. Also, greater percentage of the nitrogen in the initial material of SSC was converted into plant-available inorganic nitrogen (NH_4^+ and NO_3^-) than was achieved in HSC. Hence, most of the mineral nitrogen in HSC that was converted was lost, probably in the thermophilic phase. On the contrary, the amount of organic nitrogen contained in the finished composts of both SSC and HSC were adequately good for application to the soil. Additionally, concentrations of pathogenic microorganisms in SSC and HSC products were within acceptable limits in terms of toxicity on growing plants. The softwood sawdust compost was relatively more stable as compared to HSC under the experimental conditions. Concentrations of heavy metals in both SSC and HSC were also within acceptable limits that would cause no toxicity to plants. Also, moisture contents in both SSC and HSC were within the good range (40 - 60%) required for a good compost. Thus both SSC and HSC produced were of good quality. Further

research targeting specific wood species utilised in Ghana would help to identify composting materials which are readily degradable, as well as those that are toxic to microorganisms.

CHAPTER ONE

INTRODUCTION

1.0 Background information

One of the greatest challenges facing Ghana is effective and sustainable management of the vast amount of sawdust produced by wood industries across the country (Sawyer, 1994). With an estimated 97,000 metric tonnes generated annually in Ghana, sawdust constitutes a significant portion of solid waste produced in Ghana which in recent years has assumed public health concern (FAOSTAT, 2008). Sawdust waste contributes to contamination of urban water and also serves as breeding sites for pathogens, flies, insects and rodents (Danquah *et al.*, 2011; Boadi and Kuitunen, 2005).

The prevailing methods of disposal of sawdust (open dumping and burning) are also associated with numerous environmental hazards such as fire outbreaks, offensive odours and blocking of water ways which leads to flooding (Boadi and Kuitunen, 2002; Klinck and Stuart, 1999). Thus, effective management of sawdust is a key strategy for achieving environmental health and enhancement of disease control efforts in Ghana (Boadi and Kuitunen, 2002).

Unfortunately, various techniques adopted over the years for effective management of sawdust in Ghana have failed to produce desirable results. Consequently, huge volumes of sawdust continue to pile up and remain untreated, posing problems to the environment (Boadi and Kuitunen, 2002; Obodai and Johnson, 2002).

Composting is therefore the most viable technique for effective and sustainable management of sawdust (McGarry, 1980). Composting is the process of converting organic substrate into humus-like material which can be used as organic fertiliser or soil conditioner (Ali *et al.*, 2004). Decomposition and stabilisation of organic component of waste can be achieved through composting to produce final stable products free of pathogens and weed seeds (Haug, 1993).

From treatment oriented perspective, composting serves as an overall waste treatment option for effective management of municipal waste to reduce the risk of environmental pollution. Composting is a more economical and environmentally friendly process of waste management since it does not involve burning of fossil fuel or use of chemicals as compared to other methods such as recycling, incineration and land filling (Fobil, 2008).

Besides, composting can degrade and in some cases, completely eliminate wood preservatives and pesticides which are used for wood treatment and thus help to prevent contamination of the soil (Büyüksönmez, *et al.*, 2000). Application of compost improves soil fertility by physically loosening the soil to improve aeration and water holding capacity which in turn encourages better root growth (Larney and Hao, 2007). Good compost can supply all essential nutrients as well as microorganisms which aid in decomposing complex compounds into simple elements that can be absorbed by roots of plants (Carter and Stewart, 1996).

Compared to raw manure and synthetic fertilizers, compost has numerous benefits for improving soil properties such as maintenance of stable soil moisture content,

prevention of leaching of soil nutrients, reducing soil-borne diseases and acting as buffer to facilitate gradual release of plant nutrients (Pecchia, 1996; Leclerc *et al*., 1995; Dick and McCoy, 1993).

Currently, huge demand for compost exists in Ghana, particularly in vegetables and fruits crop production for the export market. Apart from main stream agriculture, considerable demand for compost also exists in landscaping and green house farming (Danso *et al*., 2002; Drechsel and Kunze, 2001; Stoffella and Kahn, 2001).

One problem with composting of sawdust is the high carbon-nitrogen ratio which reduces the efficiency of their degradation. High cellulose and lignin contents, coupled with low nitrogen contents lead to the depletion of nitrogen by microorganisms during the composting of sawdust (Ortega *et al*., 1996). Additionally, several tree species, such as walnut and redwood, are known to have direct phytotoxic effects on microorganisms which affect the extent of decomposition achieved from utilising sawdust in composting (Wilson and Dalmat, 1983).

However, amended with supplemental applications of nitrogen rich materials, sawdust has been identified as an excellent substrate for composting (Prempeh, 2010; Baffour-Asare, 2009).

1.2 Problem statement

With only few studies conducted to identify the most suitable amendments of sawdust produced in Ghana which gives the best output of compost, research has therefore provided limited information to enable investors to realise the full potential of utilising sawdust in composting.

This has resulted in low interest in composting of sawdust in Ghana. Consequently, with a thriving wood industry producing tonnes of sawdust on daily basis, sustainable management of sawdust wastes still remains a major challenge in Ghana (Boadi and Kuitunen, 2005; Obodai and Johnson, 2002).

1.3 Justification

Composting of sawdust would help to reduce importation of inorganic fertiliser by Ghana estimated at about eighty million (80,000,000) metric tonnes (MOFA, 2015). Indeed almost all fertilisers used in Ghana are imported which puts pressure on the local currency and domestic economy (FAO, 2005). Moreover, with high illiteracy rate of farmers in Ghana, chances of misuse of inorganic or mineral fertilisers is very high (Mensah and Larbi, 2005). Hence, continuous application of chemical fertiliser could potentially lead to negative implication on the environment and significantly detract from the benefits expected from their use (Carvalho and Malcata, 2001).

Since significant variation could exist with regards to the rate of decomposition of different wood species (Wilson and Dalmat, 1983)., comparative studies utilising softwood and hardwood sawdust produced in Ghana would also help to identify which wood species to target for producing compost. Also, physico-chemical and biological changes during composting process help to evaluate quality of the final

products (Sullivan and Miller, 2001). There is therefore the need to undertake research to assess the dynamics of physico-chemical and biological factors as well as the stability or maturity of compost produced from softwood and hardwood sawdust amended with plant materials.

1.4 Objective

The objective of this study is to evaluate the physico-chemical and biological changes, as well as the stability/ maturity of organically amended soft and hardwood sawdust composts.

CHAPTER TWO

2.0 Literature Review

2.1 Production of sawdust in Ghana

The timber industry in Ghana, comprising over 100 sawmills, 9 plymills, 15 veneer mills and over 250 furniture manufacturers scattered across the country, generates considerable amount of residues in the form of sawdust, edging, core rejects, slabs and veneer waste. Wood residues are produced at every stage in wood processing from logging to primary and secondary conversions.

With sawmilling being the least efficient of the industry (recovery rate of 34%), it is estimated that 97, 000 tonnes of sawdust is generated annually constituting 20 % to 25% of the true volumes of logs sawn whiles other residues constitute 25% to 35%. Thus, generally the residues generated from processing of wood account for about 55% of the volume of logs brought to sawmills with only 45% emerging, on the average, as wood products (Sawyer, 1994).

2.2 Pollution from sawdust waste in Ghana

In recent years, volumes of sawdust generated in Ghana have attained unacceptable levels since their utilisation is very low hence sawdust continues to pile up (Fig. 2.1). Sawdust is usually considered as waste and burnt or indiscriminately disposed posing a huge problem to the environment (Fig 2.2). Even so, production of sawdust is expected to increase as more factories continue to emerge while milling efficiency of the industry continues to remain very low.

Fig. 2.1: Sawdust pile at a wood processing factory in Kumasi.

Fig. 2.2: Indiscriminately disposed sawdust.

Rising volumes of sawdust coupled with poor disposal methods pose serious problem to the environmental. Indiscriminate disposed sawdust eventually ends up in water ways and block major drains in most urban areas. The result of this phenomenon is that with little downpour many water ways overflow causing flooding in cities (Boadi and Kuitunen, 2005).

2.3 Management of sawdust and other organic waste

Several techniques for managing sawdust have been attempted in Ghana, though most of these techniques have failed to ensure effective and sustainable management of sawdust. In 1980 a pyrolytic plant was setup in Kumasi to produce charcoal and gas to serve as alternative fuel in Ghana. This was part of research effort by the Technology Consultancy Centre of the University of Science and Technology to develop alternative fuel for brick kilns.

The products of the plant (oil, gas and powdered charcoal) were intended to provide a substitute fuel for domestic and industrial activities. The plant produced 25% and 18% of charcoal and oils respectively, depending on moisture content of the feed and efficient control of temperature of the reactors. Unfortunately lack of funds for major repairs and modification affected the operations of the plant leading to its shut down (Hagan, 1985).

Though utilisation of sawdust as a substrate for fuel is practiced in Ghana, only negligible amount of the sawdust is used for this purpose (Obodai and Johnson, 2002). Nevertheless, few of the mills have recently acquired moulding machinery for processing some of the residue into sticks, slips and narrows for export. Composting offers the most viable technique for effective and sustainable management of sawdust waste produced in Ghana (McGarry, 1980).

2.4 The concept of composting of organic waste

Activities of living organisms cycling nutrient elements between simple forms in the abiotic environment and complex forms (such as carbohydrates, proteins and lipids) in the bodies of living organisms are some of the ways of composting. Plants synthesise complex carbon containing compounds (carbohydrates, proteins and lipids) which other living organisms depend upon as a source of raw material for their growth and metabolic activities (Pecchia, 1996)).

Decomposers (such as fungi and some bacteria) obtain their nutrients by breaking down complex compounds such as starch, cellulose, proteins and lipids and in the process help to return valuable nutrients (nitrates and phosphates) to plants. Thus, activities of decomposers ensure that nutrients contained in the bodies of dead organisms are recycled.

Unfavourable conditions such as extreme temperature, pH and anaerobic conditions inhibit activities of decomposers, and thus decrease the rate of decomposition of organic matter in the natural environment (Pecchia, 2006). Composting helps to speed up the rate of decomposition of organic material under controlled (predominantly aerobic) conditions suitable for proliferation of microorganisms (UNEP, 2005).

Basically, composting involves microbial decomposition of organic materials to convert them into stable materials or humus which can be used as a soil conditioner with the release of carbon dioxide and heat. The degradation rate of organic material by microorganisms helps to synthesis humified compounds (humus) which can serve

as slow-release fertilisers for agricultural purposes. Concepts generally underlying organic composting are shown in Fig. 1.1

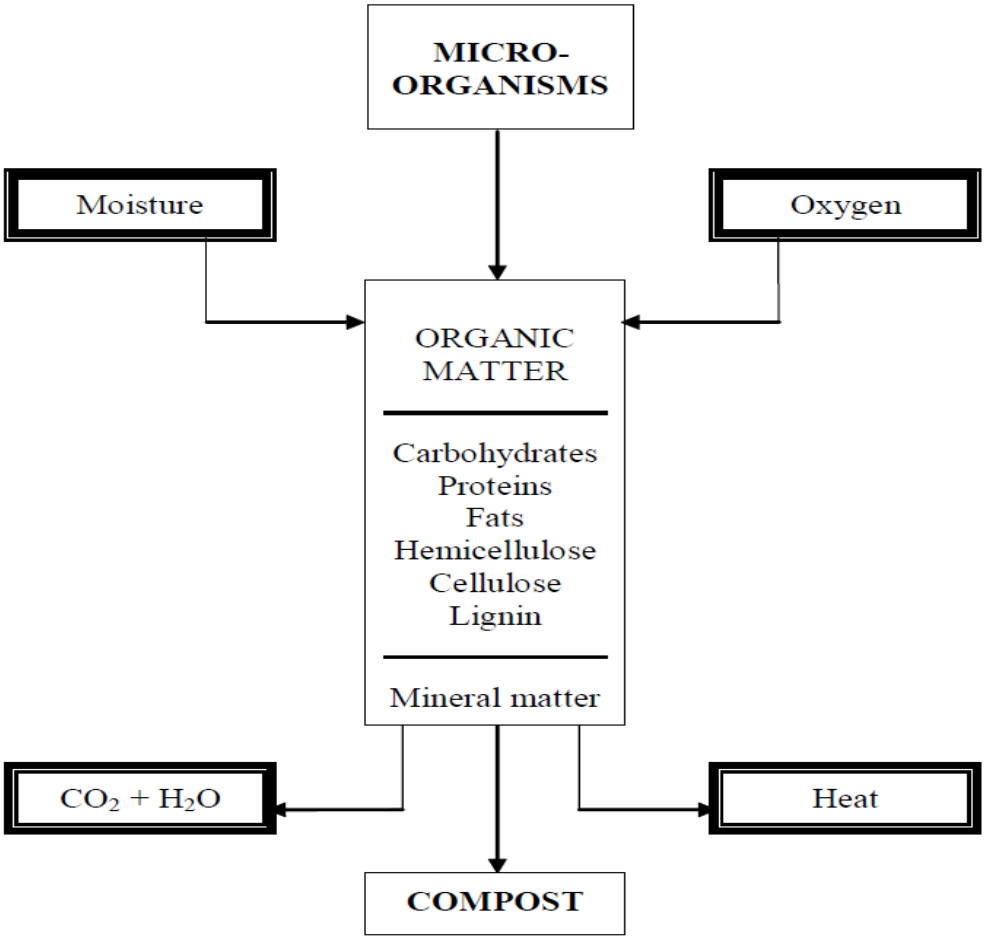

Fig. 1.1: Basic concept of composting process.

Source: Epstein, (1997).

Importance of composting

Composting helps to convert the organic components of waste into valuable products (organic fertiliser) which can be applied as a soil conditioner to supply nutrients to crops. Thus, it is a better technique for managing waste as compared to land filling and incineration (Denison and Ruston, 1990).

Application of compost helps to improve both physico-chemical and biological properties of the soil. Good quality compost improves water holding capacity of sandy soils and enhances drainage and aeration which reduces water logging conditions in heavy clay soils (Pecchia, 1996).

Compost increases the ability of the soil to hold and release essential nutrients. The activities of earthworms and soil microorganisms beneficial to plant growth are promoted with compost (Gupta *et al*., 1987). In addition, application of compost to soil enhances seedlings emergence and water infiltration due to a reduction in soil crusting. Over time, regular addition of compost creates a desirable soil structure, making the soil much easier to work.

Besides, compost helps to bind heavy metals in the soil which reduces contamination of water bodies (Barker and Bryson, 2002). Composting helps reduce the use of chemical fertilisers and thereby reduces the risk of environmental pollution Compost provides a stable organic matter that improves the physical, chemical, and biological properties of soils, thereby enhancing soil quality to achieve better yield and quality of crops (Larney and Hao, 2007; Hoornweg *et al*., 1999).

When correctly applied to the soil, compost has a beneficial effect on soil properties such as improving soil structure, increasing water holding capacity, reduce erosion and create suitable conditions for growth of roots (Risse *et al*., 2002).

2.4.2. Parameters for monitoring composting process

A number of factors need to be controlled during the composting process in order to ensure efficient degradation of the substrate material. The nature of the feedstock and the manner of composting dictates the essential properties of the compost such as C/N ratio, available macronutrients (N, P and K) and micronutrients (Fe, Mg, Mo), as well as associated micro flora and fauna (bacteria and fungi).

2.4.2.1 Physical parameters

2.4.2.1.1 Temperature

Temperature variations influence the presence and absence of microbes in compost and thus serve as an important indicator of microbial activity and the extent of decomposition achieved during the composting process. As microorganisms work to decompose organic materials heat is evolved which increases the temperature of the compost pile (Leton and Stentiford, 1990).

The temperature pattern shows the microbial activity and the occurrence of the composting process. These changes in temperature are generally categorised into mesophilic phase (20 ℃ – 45 ℃), during which bacteria and fungi decompose soluble and readily degradable compounds such as sugars and amino acids; thermophilic phase (45 ℃ – 65 ℃) whereby microorganisms degrade fats, cellulose, hemicellulose and some lignin and curing phase during which temperature falls to the ambient level due to reduction in microbial activity (Stromberger *et. al.,* 2011; Chen, 2003; Chen and Inbar, 1993). Thus, the composting process begins with bio-oxidative phase (initial mesophilic phases and thermophilic phase) and ends at the maturing phase or curing phase (Keener *et al.*, 2000).

The optimum temperature range for composting is 40 ℃ – 65 ℃ (de Bertoldi *et al*., 1983). Extreme temperatures beyond the range which can be tolerated by thermophilic organism significantly affect the rate of decomposition during composting process.

2.4.2.1.2 Aeration

Aeration is a key factor for composting. Carbon dioxide and oxygen production and consumption respectively are very useful parameters for monitoring the composting process (Tremier *et al*., 2005). Organic materials in compost are decomposed most rapidly under aerobic conditions. Poor aeration creates anaerobic conditions which are not favourable to most of the micro-organisms which degrade the organic material during composting and thus decreases the rate of decomposition. Inadequate supply of oxygen due to poor aeration also results into the proliferation of anaerobic microorganisms leading to the production of foul odour and toxic chemicals in the compost (Stanley and Turner, 2010).

Proper aeration controls the temperature, removes excess moisture and carbon dioxide (CO_2) and provides oxygen (O_2) for the microorganisms to enable them to undergo respiration in order to obtain energy for their activities. The optimum O_2 concentration is between 15 and 20% (Miller, 1992). Controlled aeration maintains temperatures within 60 – 65℃ which ensures good supply of O_2 to aerobic microorganisms (Finstein and Miller, 1985).

2.4.2.1.3 Moisture

Variation in moisture content of a compost heap is very important during the

composting process. Microbial activities usually decrease under dry or water-logged conditions. Though water content varies with the nature of the material being composted, it is generally accepted that 40 % – 60 % of moisture is required to ensure rapid decomposition of the compost material (Gajalakshmi and Abbasi, 2008).

The organic materials do not decompose rapidly when moisture content is below 40% and above 60%, as air flow into the compost heap is restricted thereby limiting the decomposition of organic materials (Das and Keener, 1997).

2.4.2.1.4 pH

Composting involves different types of bacteria and other living organisms, each suited to specific acidic or alkaline environment of relatively limited duration within which active decomposition occurs. Most bacteria are active within the pH range of 6.0 - 7.5, whereas fungi work best at the pH range of 6 – 8. Also N availability occurs at the pH range of 6 to 8. Thus, pH affects the composting process by controlling the microbial population and availability of nutrients to microbes, hence determines the extent of decomposition achieved at the various stages of composting.

According to Meunchang *et al*. (2005), during composting the microbes initially produce acidic compounds but as the temperature increases and oxygen becomes limited, ammonia is released which increases the pH to alkaline level. At maturity, pH drops as most of the ammonia is lost or used up in the heap and organic carbon is mineralised by acid forming bacteria due to nitrogen limitation (Meunchang *et al*., 2005)

A pH range of 5.5 to 9.0 supports good microbial activity during composting, but optimum pH values range from 6.7 to 8.0 (de Bertoldi *et al*., 1983; Miller, 1992). pH

is not a key factor for composting since most materials are within suitable range. However, this factor is very relevant for controlling N-losses by ammonia volatilisation, which can be particularly high at pH > 7.5 (Khan *et al*., 2009). According to Khan *et al*. (2009) pH below 5 indicates that a compost sample is acidic; 5 to 7.5 is neutral and above pH 7.5 is alkaline. Amendment with elemental sulphur (S) helps avoid excessively high pH during composting (Mari *et al*., 2005).

2.4.2.1.5 Particle Size

Decomposition occurs primarily on or near the surfaces of particles, where oxygen diffusion into the aqueous films covering the particle is adequate for aerobic metabolism, and the substrate itself is readily accessible to microorganisms and their extracellular enzymes. Small particles have more surface area per unit mass or volume than large particles; small particles will degrade more quickly in the presence of adequate aeration (Bernal *et al*., 1993).

Particle size also affects the availability of carbon and nitrogen. Large wood chips, for example, provide a good bulking agent that helps to ensure aeration through the pile, but they provide less available carbon per mass than they would in the form of wood shavings or sawdust. The smaller the size of the organic refuse particle, the more quickly it can be consumed by the microbes.

2.4.2.2 Biological parameters

Compostable materials normally contain a large number of many different types of bacteria, fungi, moulds and other living organisms. Each of these organisms is suited to a particular environment of relatively limited duration and each is most active in decomposition of some particular types of organic matter (Cole, 1995).

During the composting process, the soluble organic matter in the starting material is initially assimilated by the microorganisms; once the soluble organic matter is used up, microorganisms produce hydrolytic enzymes which depolymerise the larger compounds (lignin, cellulose, hemicellulose) to smaller fragments that are water soluble (Tate, 1995; Tiquia *et al*., 2002).

The water soluble components dissolve in the water and are finally assimilated by the microorganisms. Colin (1978) indicated that hydrolytic enzyme activity (amilasic, cellobiasic, and proteolytic) increases gradually during composting, but decreases slightly at the end of the process, concluding that when enzymatic activity stabilizes, the compost may be considered sufficiently mature.

Studies by Gotaas (1976) have indicated that no supplementary inoculum is needed in a compost pile. More species of bacteria are involved in aerobic decomposition than in anaerobic putrefaction. Aerobic composting is a dynamic process which combines the activities of a wide succession of mixed bacterial, actinomycetes, fungal and other biological populations.

Since each of the organisms is suited to a particular environment of relatively limited duration and each is most active in decomposition of some particular type of organic matter, the activities of one group complement those of the other. Soil invertebrates such as termites, worms and ants, also have been reported as colonizing compost pile and contributing to the decomposition process (Anderson, 1982).

Substantial changes occur in microbial populations and species abundance during the various temperature stages in composting (Gupta *et. al.,* 1987). Mesophilic bacteria

and fungi are dominant in the initial warming period. Thermophilic bacteria (especially actinomycetes) become dominant during the high temperature phase, and mesophilic bacteria and fungi during the curing phase (Finstein and Morris, 1975).

Aerobic composting is a dynamic process which combines the activities of a wide succession of mixed bacterial, actinomycetes, fungal, and other biological populations. Besides C source, microorganisms require macronutrients such as N, P and K, and trace elements for their growth. Nitrogen is a critical element for microbial growth and therefore if N is limiting during composting the degradation process will be slow (Ryckeboer *et al*., 2003).

2.4.2.3 Chemical parameters

2.4.2.3.1 Carbon: Nitrogen (C: N) ratio

Microorganisms that decompose plant materials require considerable carbon and nitrogen for the formation of protein and other constituents in their bodies. Besides providing energy for microorganisms, carbon also combines with nitrogen in building cell protoplasm hence more carbon (30 parts) is needed than nitrogen (one part) during composting (Wilson and Dalmat, 1983).

Initial C/N ratio ranging from 25:1 to 30:1 ensure that the nutrients required by microorganisms for the composting process are supplied in adequate proportions. Lower C/N ratios (below 25:1) increase the loss of nitrogen through volatilisation of ammonia. On the other hand, high ratios (above 30:1) reduce the efficiency of degradation of the substrate material and hence prolong the composting period. The

C/N ratio considers the available carbon as well as the available nitrogen (Larsen and McCartney, 2000).

2.4.3 Parameters used in assessing quality of organic compost.

Compost characteristics desired by end users vary, but most compost users look for essential qualities such as moisture content, odour, feel, uniform texture, stability, nutrient concentration, product consistency, phototoxic compounds and other contaminants. Therefore thorough evaluation of compost quality is based on physico-chemical parameters as well as bioassay assessments (germination test).

Physical factors include pH, temperature, moisture, colour, odour, water and air retention capacities (Garcia *et al*., 2007), while chemical parameters usually comprise concentrations of toxic elements, electrical conductivity, C: N ratio, cation exchange capacities, water-soluble organic matter level and humification indexes.

2.4.3.1 Physical parameters

Odour is generally the most serious complaint from neighbours of compost facilities (Cole, 1995). Compost that is properly made under aerobic conditions will have an earthy aroma that is not offensive. However, partly decomposed feedstocks can generate problematic odours including ammonia, hydrogen sulphide (rotten egg smell), and volatile fatty acids (Dindall, 1971).

An ammonia smell is usually generated in a compost pile that contains too much nitrogen-rich material such as fresh grass. Ammonia can also be generated when carbon has been supplied to the piles in particles that are too large. Also ammonia odour can sometimes indicate a pH level that is too high. A smell of hydrogen sulphide (rotten egg) indicates that anaerobic conditions are present within the

compost pile. This is either because the material is too wet or there is insufficient aeration (Hernandez *et al*., 2006).

Chemical parameters

Also important is the amount of organic nitrogen left in the compost since this nitrogen form is unavailable to plants. Too high amount of organic nitrogen in finished composts maintains high decomposition activity by soil microorganisms, which may retard plant growth due to nitrogen starvation and phytotoxicity of ammonia. On the other hand very low amount of organic nitrogen promote anaerobic conditions and release organic acids which increases soil acidity (Fang *et al*., 1999).

Limited nitrogen or too much carbon affects the proliferation of microorganisms hence the pile breaks down too slowly. Therefore, high carbon-nitrogen ratio rapidly slows down the rate of decomposition. However, low C/N ratio leads to excess ammonia formation which increases the pH and thereby enhances ammonia volatilization (Hernandez *et al*., 2006). Ideally, C/N ratio below 20:1 in the final compost is adequate for application to the soil (Sullivan and Miller, 2001).

Another important measurement of compost quality is salinity, estimated by measuring the electrical conductivity. When the level of salt in the compost is high, crop growth and productivity are reduced. As salinity increases, salt accumulation in the root zone increases to a level at which plant root can no longer extract sufficient water from the soil and compost solutions.

Contamination from toxic elements (heavy metals) in compost can lead to accumulation of toxic chemicals at higher tropic levels. Application of compost

containing excessive amount of toxic elements may have negative implications on the health of humans. Beyond permissible threshold, heavy metals, such as lead (Pb), cadmium (Cd) and mercury (Hg) are known to have direct effect on living organisms, which is a major problem in compost derived from mixed materials in the waste streams (Wu *et al*., 2000).

From ecological point of view, it is desirable that the levels of toxic elements which are not essential for plant growth are considerably reduced in final compost in order to prevent contamination of water bodies or from being absorbed by plants.

Beside sanitary quality, compost used in agriculture should also meet ecological standards preferably low concentration of heavy metals. Due to their phytotoxic effect on crops and other organisms through bioaccumulation at higher trophic levels in the food chain knowledge of the amount of toxic elements (heavy metals) in compost is very important from ecological point of view.

2.4.3.2 Indicators of compost stability and maturity

Beside the amount of plant nutrients obtained during composting process, proper knowledge of stability and maturity of the final products is essential for successful utilisation of composts in crop production.

Maturity relates to phytotoxicity effect of composts on crops with respect to presence or absence of phytotoxins (Bernal *et al*., 1993). Stability refers to the rate of biological activity upon application of compost to the soil which is dependent on the degree of degradation achieved during composting process, (Hue and Liu, 1995).

Application of immature or unstable composts may have a negative impact on plant growth (Wu *et al*., 2000; Epstein, 1997; Iannotti *et al*., 1993). Immature compost, maintains high decomposition activity on soils which may retard plant growth due to nitrogen starvation, anaerobic conditions and phytotoxicity of ammonia or some organic acids ((Alidadi, 2008; Fang *et al.*, 1999). Therefore, good compost should be both mature and stable.

Proper assessment of compost maturity and stability are key factors for predicting potential benefits that should be expected from application of composts to promote crop growth. Evaluation methods used to predict plant behaviour to application of different growth media may usually include complex analytical techniques such as Spectroscopic analysis (NMR, FTIR and fluorescence) (Domeizel *et al*., 2004; Chen and Inbar, 1993) or biochemical procedures (Total and specific enzyme activity) for detecting and quantifying phytotoxic molecules (Ortega *et al*., 1996).

However, rapid tests such as humus colour, CO_2 emission and germination tests which are sensitive to potentially toxic elements are usually used for assessing compost quality in order to predict plant growth response (Ofosu-Budu *et al.*, 2010; Domeizel *et al*., 2004).

Research shows that composts which pass other maturity parameters may fail germination test hence, germination test is the most useful and commonly used method in assessment of maturity and stability of composts (Ofosu-Budu *et al.*, 2010). Germination tests are used to detect excess salinity and presence of phenolic compounds in composts (Handreck and Black, 1991; Zucconi *et al*., 1981).

2.4.3.2.1 Coliforms as indicator organisms in quality of compost

A good operation of aerobic composting should be able to kill all pathogenic microbes, weeds and seeds especially if the temperature can be maintained between 60 and 70 degrees for 24-hour period.` The presence of coliform bacteria is often used as an indicator of overall sanitary quality of compost. Use of an indicator such as total and faecal coliforms, against actual disease causing organisms is advantageous as the indicators generally occur at higher frequencies than the pathogens and are simple and safer to detect (Hue and Liu, 1995).

2.4.3.2.2 Helminth eggs as indicator organism in quality of compost

Helminth eggs are the most resistant of the entire group of pathogens. They can survive in the environment for many months, and are very resistant to high temperatures (Feachem *et al*., 1983). It can therefore be assumed, that if all helminth eggs in the compost are dead, all other pathogens have been removed as well. Consequently, levels of helminth eggs serves as an important indicator for estimating concentration of other potential harmful pathogens in final composts.

2.4 Composting Methods

Various techniques have been deployed for managing the composting process in order to improve upon the quality of the end-products. These include vermicomposting, aerated (Turned) windrow composting, aerated static pile composting, in-vessel composting and co-composting. There are three basic types of composting – anaerobic, aerobic, and vermi-composting.

2.4.1. 1 Aerobic composting

Aerobic composting is a dynamic process which involves combined activities of a wide succession of mixed bacteria, actinomycetes, fungal and other biological populations which require oxygen. Bacteria, actinomycetes and fungi are the most active microorganisms in aerobic composting (Gupta *et al.*, 1987).

2.4.2 Aerated (turned) windrow composting

For the aerated windrow composting, organic waste is formed into rows of long piles called windrows and aerated by turning the pile periodically, manually or by mechanical means. The ideal pile height, which is between 4 and 8 feet, allows for a pile, large enough to generate sufficient heat and maintain temperatures, yet small enough to allow oxygen to flow to the windrow's core (Fraser and Lau, 2000). This method can accommodate large volumes of different wastes, including yard trimming, grease, liquids, and animal byproducts such as fish and poultry wastes, but only with frequent turning and careful monitoring.

This method is suited for large quantities, such as waste generated by entire communities and high volume food-processing businesses e.g., restaurants, cafeterias, packing plants.

In a warm, arid climate, windrows are sometimes covered or placed under a shelter to minimize evaporation. However, in rainy seasons, the shape of the pile is adjusted so that water runs off the top of the pile rather than being absorbed into the pile. Also, windrow composting can work in cold climates. In addition, windrow composting is a large scale operation and might be subjected to regulatory enforcement. Samples of the compost are tested in laboratories for bacterial and heavy metal content. Odour is also controlled.

Other concerns might include zoning and sitting requirement. Windrow composting often requires large tracts of land, study equipments, a continual supply of labour to maintain and operate the facility, and patience to experiment with various material mixtures and turning frequencies. This method yields significant amount of compost, which might require assistance to market the end-product. Alternatively, the local governments can make the compost available to residents for a low or no cost.

2.4.3 Aerated static pile composting (ASPC)

In aerated static pile composting, organic waste is mixed together in one large pile of composting heap instead of rows. To aerate the pile, layers of loosely piled bulking agents (wood chips, shredded newspapers) are added so that air can pass from the bottom to the top of the pile. The pile also can be placed over a network of pipes that deliver air into or draw air out of the pile.

A literature study indicates that aeration in composting is to satisfy the oxygen demand, often aerobic decomposition, remove excess moisture and excess heat (Keener, 1997). Appropriate aeration will enhance effective microbial activities during decomposition process.

Aerated static piles of organic wastes are suitable for a relatively homogenous mix of organic waste, and work well for larger quantity generators of yard trimmings and compostable municipal solid waste. However, this method does not work well for composting animal byproducts or grease from food processing industries.

Like windrow composting, in a warm, arid climate, aerated static piles are sometimes covered or placed under a shelter to minimize water evaporation. In the cold, the core

of the pile will retain its warm temperature, but aeration might be more difficult because this method involves passive air flowing rather than active turning. Some aerated static piles are placed indoors with proper ventilation.

Since there is no physical turning, ASPC requires careful monitoring to ensure that the outside of the pile heats up as much as the core. One way to alleviate bad odors is to apply a thick layer of finished compost over the pile, which can help maintain high temperatures throughout the pile. Another way to deal with odour, provided that the air blower draws air out of the pile, is to filter this air through a bio-filter made from finished compost.

This method requires equipment such as blowers, pipes, sensors, and fans which might involve significant costs and technical assistance. Having a controlled supply of air enables construction of large piles, which require less land than the windrow method. This method produces compost relatively quickly-within 3 to 6 months.

2.4.4 In-vessel composting

Organic materials are fed into a drum, silo, concrete-lined trench, or similar equipment where the environmental conditions-including temperature, moisture, and aeration are closely controlled. The apparatus usually has a mechanism to turn or agitate the material for proper aeration. In-vessel composters vary in size and capacity. It can process large amount of waste without taking up as much space as the windrow method. In addition, it can accommodate virtually any type of organic waste such as meat, animal manure, bio-solids and food scraps (Sihna *et. al*., 2010).

Some in-vessel composters can fit into a school or restaurant kitchen while others can be so large as to accommodate large food processing plants. In-vessel composting can be used year-round in virtually any climate because the environment is carefully controlled, often by electronic means. This method can even be used in extremely cold weather if the equipment is insulated or the processing takes place indoors. It produces very little odour and minimal leachate (Kalamdhad and Kazmi, 2009).

However, in-vessel composters are expensive and require technical assistance to operate properly, but this method uses much less land and manual labour than windrow composting. Conversion of organic material to compost can take as little as a few weeks. Once the compost comes out of the vessel, however, it still requires a few more weeks or months for the microbial activity to stabilize and the pile to cool (Huang *et al*., 2004).

2.4.5 Co-composting

The term co-composting means composting two or more materials together. This kind of composting is advantageous because the materials involved usually complement each other (Gallizzi, 2003). The garbage (sawdust and market waste) have high organic/carbon content whilst human and animal waste are high in nitrogen and moisture. This practice is also an environmentally sound solution that can reduce the risk associated with the management of organic waste by decreasing their volume and destroying any pathogenic organisms present.

Furthermore, studies conducted on greenhouse gas emissions depict the fact that emissions of these gases from composting systems are much lower than those from landfills. Having assessed the various methods of waste management that have been

proposed by the various authors, literature has further revealed that composting is the more economical and effective way of waste management in a country like Ghana.

Compost amendments is a principal factor for modifying physical and microbial condition in order to influence decomposition rate during composting: moisture content, free air space, , temperature, C:N ratio and oxygen concentrations (McCartney and Eftoda, 2002; Fraser and Lau, 2000).

2.4.1. 2 Anaerobic composting

Anaerobic composting is the breakdown of organic matter by reduction in the absence of oxygen where end products such as methane (CH_4) and hydrogen sulfide (H_2S) are released. Anaerobic decomposition of organic matter is often associated with the formation of foul smelling sulfur-containing gasses such as indol, skatol and mercaptans (Gotaas, 1976).

This method of composting involves little or no work but, maturation of the pile is usually prolonged and the process does not generate enough heat to safely kill pathogens and weed seeds. The process usually takes place at temperatures between 8 ℃ and 45 ℃, with mesophilic microorganisms breaking down the soluble and readily degradable compounds.

2.4.1 Vermicomposting

This involves the use of earthworms to decompose organic waste. Decomposition of the complex molecules in the organic material is carried out by microorganisms present in the guts of earthworms. The earthworms feed on the organic materials and change them into smaller fragments which increase their surface area to speed up the

rate of degradation by the microorganisms. The material that passes through the worms' bodies (‘‘castings”) can contain five times more nitrogen, seven times more phosphorus and eleven times more potassium than ordinary soil (Sihna *et. al*., 2010).

Worms are very sensitive to extreme conditions, therefore high pH and direct sunlight affects their activities and thus decreases the rate of decomposition of the substrate material. Temperature ranging from 15℃ – 25℃ and 60% – 75% of moisture ensure effective decomposition by earthworms (Dominquez *et al*., 2010). Extreme conditions such as temperatures above 30℃ or below 15℃ lead to migration of the worms into the inner layer of the compost for protection. Common worm species used in vermicomposting are *Eisenia fetida* and *Eisenia andrei* due to their high tolerance to high temperature. These worm species are also distributed worldwide and easily colonise organic waste materials.

Vermicomposting requires worms, worm bedding (shredded newspaper, cardboard) and a bin to contain worms and organic matter. Maintenance procedures include preparing bedding, burying garbage, and separating worms from their castings (Ortega *et al.*, 1996). Typically three to four months are required for the worms to produce harvestable castings. Vermicomposting also produces worm tea, a high-quality liquid fertiliser which is usually used in gardening.

2.4.4.1 Chemical composition of hardwood and softwood

Wood is essentially composed of cellulose, hemicelluloses, lignin, and extractives, each component contributing to the rate of microbial decomposition during composting and thus ultimately impact on properties of product obtained at the end of

the process. Relationship between chemical compositions and rate of degradation has been demonstrated. Studies indicate that the extent of decomposition achieved during composting of sawdust waste is related to the content of cellulose hemicellulose in the wood species utilised (Kalamdhad and Kazmi, 2009).

Cellulose contributes 40% – 45% of the chemical component of wood on dry weight basis. The molecular structure of cellulose imparts its characteristic properties; hydrophylicity, chirality, degradability, and broad chemical variability initiated by the high donor reactivity of hydroxyl groups. Cellulose has a strong tendency to form intra- and inter-molecular hydrogen bonds by the hydroxyl groups which stiffen the straight chain and promote aggregation into a crystalline structure and give cellulose a multitude of partially crystalline fiber structures and morphologies.

The presence of crystalline cellulose and the size of the elementary fibrils work together to produce interesting combination of contrary properties such as stiffness and rigidity as well as flexibility of the wood. Crystalline cellulose has a very limited accessibility to water and chemicals, hence microbial attack can be expected to occur primarily on amorphous cellulose and crystalline surface (Sinha *et al*., 2010).

Cellulose is a constituent of organic matter and is the key component of cell. It plays a major role in N immobilisation since it breaks down very rapidly and has a high C : N ratio. Hardwood trees have denser cell walls and contain greater amount of cellulose (up to 40%) as compared to that softwoods (5%) (Brown *et al*., 1998).

Lignin is another component of organic matter and is closely associated with cellulose. However, it is more resistant to decomposition than cellulose.

Consequently, knowledge of chemical composition of the tree species from which sawdust is obtained as well as the most suitable amendment of sawdust is important in composting of sawdust.

2.5 Composting of sawdust

Blending of high C:N feedstocks with low C:N feedstocks is one strategy used to increase decomposition rates. Over the years, several researchers have attempted co-composting of sawdust with a wide range of materials (such as food waste, sewage sludge, liquid waste and farmyard manure) in order to improve upon the efficiency of composting of sawdust (Costello and Suvillan, 2011; Kalamdhad and Kazmi, 2009; Huang *et al*., 2004; McCartney and Eftoda, 2002; Fraser and Lau, 2000). The outcomes of previous research effort show that the amendments of sawdust is a principal factor for modifying physical and microbial conditions in order to influence decomposition rate and thus the extent of degradation achieved during the process.

Though very little research on composting of sawdust has been undertaken in Ghana, some attempts have been made in previous research work (Prempeh, 2010; Obodai *et al*., 2010; Baffour-Asare, 2009) on co-composting of sawdust with amendments from other plant materials. This notwithstanding, knowledge on the most suitable amendment of sawdust which gives the best output of compost is still lacking in Ghana.

CHAPTER THREE

3.0 Materials and Methods

3.1 Location of the experimental site

The experiment was conducted at three locations namely, Soil and Environmental Sciences Research Centre of the Biotechnology and Nuclear Agriculture Research Institute (BNARI) of Ghana Atomic Energy Commission (GAEC), Kwabenya near Accra, Eco-lab of University of Ghana and Animal Research Institute of the Council for Scientific and Industrial Research (CSIR), Accra. The compost was formulated at the Soil and Environmental Sciences Research Centre, BNARI.

Analyses of the elemental composition and concentration of pathogens in the compost were conducted at Eco-lab of University of Ghana and Animal Research Institute, Council for Scientific and Industrial Research (CSIR), respectively.

3.2 Experimental material and sample collection

The experimental materials comprise 500 kg each of sawdust produced from common hardwood and softwood species utilised in Ghana, mucuna leaves, food waste and 12 barrels of effluent (animal liquid waste) (Fig. 3.1).

Fig. 3.1 a: Samples of effluent and food waste used for the experiment

Fig. 3.1 b: Mucuna leaves used to amend the sawdust to form the compost heaps.

The softwood species consist of *Triplochiton scleroxylon* (Wawa), *Alstonia boonei* (Nyame dua), *Antiaris toxicaria* (Kyenkyen) and *Ceiba pentandra* (Ceiba). The hardwood species were *Terminalia lvorensis* (Emire), *Terminalia Superba* (Ofram), *Celtis mildbraedii* (Celtis), *Piptadeniastrum africanum* (Dahoma). These timber/tree species are commonly used by the wood industry in Ghana.The sawdust were collected from small scale saw millers at Amasaman whilst mucuna leaves, kitchen waste and effluent were obtained from Ghana Oil Palm Company, Kade, some hotels and restaurants within Accra and J'FAMCO Abattoir at Madina, respectively.

3.3 Formulation of compost heap

Aerobic decomposition process was used for the formulation of the compost in addition to manual turning of the waste pile in constructed windrows. This method accommodates large quantities of organic waste and still maintains optimum aeration and temperature regimes due to frequent turning of the heap (Hoitink *et al*., 1993).

Two compost heaps (hardwood sawdust compost and softwood sawdust compost) were prepared for the study. Each heap comprised 500 kg of sawdust and 167 kg each

of mucuna leaves and the kitchen waste in a ratio of 3:1:1 on weight basis and heaped using the effluent from abattoir till the moisture content of the heap formed was about 65%.

Fig. 3.2: Compost heaps formulated from sawdust, food waste and mucuna leaves.

Source: Field experiment 2014

3.4 Monitoring of the compost heap

3.4.1Determination of temperature and moisture

Temperature and moisture content of the heap were monitored by the use of a probe thermometer (Eric Crouch, George Longmuir- America) on daily basis and the heap was turned at three day intervals in order to maintain optimum aeration and temperature. Likewise, moisture content was monitored on a daily basis using the gravimetric determination method.

3.4.2 Determination of pH

Samples of composts were taken, air-dried and ground to pass through a two millimetres (2 mm) sieve. A mass of 0.1 g of the ground sample was weighed into a 50 ml beaker and 50 ml of distilled water was added. The suspension was stirred several times with a glass rod for 10 minutes and then allowed to settle for 30 minutes. After this the electrode of the pH meter was inserted into the supernatant of samples to determine pH using an Alpha 500 model laboratory pH/mv meter. Buffer solutions of 4 and 7 were used to standardise the pH meter.

3.5 Laboratory analyses

3.5.1 Sampling method

Each compost heap was segmented into three layers namely top layer, middle layer and bottom layer. Samples for analyses were taken from these three layers using a sterile spatula at two weeks intervals for a period of 12 weeks. For uniformity of results, each layer was thoroughly mixed before sampling and analytical readings from the three layers were averaged.

3.5.2.2 Determination of bacteria load

The methods used for these procedures were modified by Anderson, (1982).

3.5.2.2.1 Total viable count (TVC)

Pour-plate method was used for the Total Aerobic Mesophilic Bacteria (TAMB). One milli litre (1 ml) of each dilution was aseptically added to 9 ml of molten standard plate count agar (Merck, Darmstadt-Germany) and kept at 45 – 50℃ in a water bath (Grant, OLS 200). The mixture was poured into a 9 cm sterile petri dish, allowed to settle and cool. The mixture was incubated at 37℃ for 18 - 24 hours. The procedure was repeated for each sample in triplicates.

3.5.2.2.2 Total coliform count (TCC)

Using the plate-count method, one (1) ml of neat (suspension) was aseptically put into 9cm petri dish. Nine (9)ml of molten Violet Red Bile agar (VRBA) [EOS Laboratories] kept at 45 - 50℃ in a water bath was added, mixed by swirling and allowed to settle and cool. Plates were incubated at 37℃ for 48 hours and made ready for reading.

3.5.2.2.3 Faecal coliform count (FCC)

Using the plate count method, between 0.1 and 0.5 ml of each suspension was aseptically put into 9cm petri dish. Nine (9) ml of Eosin Methylene Blue Agar (EMBA) [Scharlau Chemie, 01 - 068, Spain] kept at 45 - 50℃ in a water bath was added, mixed by swirling, allowed to cool and set. Plates were incubated at 45 ℃ for 24 - 48 hours.

3.5.2.2.4 *Escherichia coli* count (ECC)

The technique for the FCC was employed for ECC except that only colonies showing metallic sheen were counted.

3.5.2.2.5 *Salmonella* count (SC)

One (1) ml of each sample was added to 20 ml of double strength Selenite Flouride (SF) broth [Oxoid, CM395, and L.121 Hamphire-England], mixed thoroughly and incubated at 37 ℃ overnight. One (1) ml of the culture (SF broth) was serially diluted using 10-fold serial dilution into five (5) other sterile MacCartney bottles containing 0.1% 9ml peptone water.

Using the pour-plate technique, 1 ml of diluents was aseptically added to 9 ml of molten Salmonella Shigella Agar (SSA) [Oxoid, CM 533, Hamphire-England] and kept at 45 - 50℃ in a water bath, mixed by rotation and incubated at 37℃ for 24 hours.

3.5.2.3 Culture of bacteria load

From each of samples prepared, a sterile loop full of the neat (suspension of compost and peptone water) was aseptically streaked onto blood agar [Merck, Darmstadt-Germany] and Mac Conkey agar [Merck, Darmstadt-Germany] using the plate-out technique. Cultures were incubated aerobically and anaerobically at 37℃ for 18 – 24 hours in a bacteriological incubator.

3.5.2.4 Isolation and identification

Colonial morphology of organisms, based on their physiological characteristics was studied for size, shape, outline, colour and change in medium on various compost samples. Standard microbiological techniques including staining, cellular morphology biochemical tests such as Motility Indole Urea (MIU), Catalase and Triple Sugar Iron (TSI), Carbohydrate O/F test were used to isolate and identify food poisoning organisms such as *Salmonella* species and *Escherichia coli*. These organisms were identified by gram staining and examined using light microscope at x100 with oil immersion [Biomereiux, Etoile- France].

For the bacteria load count, plates showing between 30 - 300 colonies were selected and counted as described by Anderson (1982) using electronic colony counter [Stuart Scientific].

The number of colonies counted was multiplied by the dilution factor to obtain the total number of colonies and results were expressed as

$$TNC = NCC \times 10^{y} \text{ cfu / ml.}$$

Where, NCC = number of colonies counted

y = dilution factor and

cfu/ml = coliform unit per millilitre.

3.5.3 Helminth eggs analysis

The helminth eggs analysis was done using the Simple floatation technique as described Brown *et al*. (1998). Three (3) grammes of each compost sample was added to 42 ml of water and mastered in a pestle and mortar. The resulting mixture was strained using a coffee strainer to get rid of debris. The suspension was poured into a plastic test tube and made to the 45 ml mark to give 1:15 dilution and centrifuged briefly.

After centrifuging, the supernatant was decanted and topped up with distilled water to the 45 ml mark and centrifuged again. A pipette was used to draw some of the fluid from the resulting suspension and fed into a McMaster counting chamber for quantification of eggs of pathogens in the sample. Saturated sodium chloride solution was used as a floatation medium.

Total number of eggs counted = number of eggs counted per gram of compost x 100 (microscopic magnification)

3.6 Determination of elemental composition

3.6.1 Determination of nitrogen (N), phosphorous (P) and potassium (K).

3.6.1.1 Nitrogen

One gramme of each compost sample was weighed into a clean dry conical flask and

4 ml of concentrated H_2SO_4 was added while swirling the flask carefully to ensure that the entire sample is wetted. The content in the flask was digested (heated on an electric hot plate set at 'medium' heating in a fume hood) as described by Anderson (1982).

Ten drops of H_2O_2 were slowly added to the content after digestion and the flask was swirled for some time keeping the content at the bottom and reheated but not so excessive to avoid spattering. More drops of H_2O_2 were added until the colour of content changed from black to dark brown and then to colourless.

This resulting mixture was heated again for 10 − 15 minutes and allowed to cool. After cooling, the content was transferred into 100 ml volumetric flask and topped up with distilled water to the 100 ml mark. This solution was used to determine N, P, K contents.

Distillation and titration: Free ammonia was liberated from solution by steam distillation in the presence of excess alkali (NaOH). The distillate was then collected in a receiver (50 ml conical flask) containing excess boric acid to trap the ammonium that is evolved in the distillation process and drops of mixed indicator (bromocresol green). Five (5) ml aliquot of sample solution (digest above) was transferred into a Markham distillation apparatus.

This was followed by the addition of 5 ml of 40% sodium hydroxide, and 100 ml of distilled water. Also, 400g of NaOH were carefully dissolved in distilled water and then diluted to 1.0 litre = 40% of NaOH**.** The mixture was distilled, and the distillate collected in 5 ml of 2% boric acid indicator (2g of boric acid in 100 ml of distilled water). The distillate was titrated with 0.01 M HCl from greenish to reddish end point.

Percent nitrogen (% N) in the compost was estimated as

$$\%\ N\ \text{in compost sample} = \frac{\text{Titre Value} \times \text{mHCl} \times 14 \times v \times 1000}{al \times wt}$$

Where, v = final volume of the digestion = 100 ml

wt = weight of the sample taken in grams

al = aliquot of the solution

14 = Molar weight of nitrogen

3.6.1.1 Total Phosphorus

Total phosphorus was determined using ascorbic acid reductance method described by Webster, 1984. Two colorimetric procedures for P measurement were employed using the digest, the first procedure required that pH of the digest be at the neutral point and the second not at neutral point.

The underlying principle of the ascorbic acid reductance method was based on the colour formed by the reduction of ammonium phosphomolybdate [$(NH_4)_3$ $PO_4 12MoO_3$] complex by ascorbic acid, in the presence of antimony potassium tartarate. Once the [$(NH_4)_3$ $PO_4 12MoO_3$] blue colour was developed it became extremely stable at room temperature.

Five (5) ml of the supernatant clear wet-ashed digest solution was pipetted into a 50 ml volumetric flask. About 20 ml of distilled water were added to each flask. Ten (10) ml of the ascorbic acid reducing agent was also added to each flask, beginning with the standards. Distilled water was then added to the mark on the 50 ml flask and

shaken well for some time. This was allowed to stand for 1 hour to permit colour development. The standards and sample absorbence (blue colour) were measured at 880 nm wavelength setting in the Atomic Absorption Spectrophotometer (AAS).

Additionally, 1, 2, 3, 4, 5, and 6 ml of the 10 ppm P wet-ashed digest solutions were pipetted into 50 ml volumetric flasks and 10 ml of the ascorbic acid reducing solution were added to each flask and filled to the 50 ml mark with distilled water. These prepared solutions were left to stand for one hour after which absorbance readings were taken. The standards containing 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 ppm P were used to calibrate the Atomic Absorption Spectrophotometer (AAS) which was used to determine phosphorus in sample.

Phosphorus in sample was estimated as:

$$\%\ \mathrm{P}\ \text{in compost sample} = \frac{\text{Spectrophotometer reading} \times \mathrm{v} \times 100}{\mathrm{al} \times \mathrm{wt} \times 1000000}$$

Where, v = final volume of the digestion

wt = weight of the sample taken in grams

al = aliquot of the solution

100 =

10^6 =

3.6.1.2 Potassium (K)

Potassium in compost sample was analysed by the use of Atomic Absorption Spectrophotometer. Two (2) ml of the wet digested sample solution was pipetted into a 50 ml volumetric flask. This was then topped up with distilled water to the 50 ml

mark on the flask. The solutions were sprayed, starting with blank and standards, directly into the flame of the flame photometer for K determination. The flame photometer was set at the wavelength of 766.5nm.

Potassium in samples was estimated as:

$$\%\ \mathrm{K\ in\ compost\ sample} = \frac{\mathrm{K\ reading} \times \mathrm{v} \times 100}{1000000 \times \mathrm{wt}}$$

Where, wt = the weight of sample

v = volume of the digest solution

k reading = reading on the flame photometer.

3.6.2 Organic carbon

The organic carbon content was analysed using the Walkley-Black method as modified by Webster, 1984. The value for the organic-C content of compost was expressed as organic matter by multiplying the figure for organic-C by the conventional 'Von Bemmlen' factor of 1.724.

A 0.1g of compost was put into a 250 Erlenmeyer flask and 10 ml of dichromate solution was added, followed by 20 ml of concentrated H_2SO_4. The flask was swirled for the solution to be in contact with the particles of compost and allowed to stand on an asbestos sheet for 30 minutes. Two hundred ml of distilled water, 10 ml of ortho phosphoric acid and 2 ml of barium diphenylamine sulphate indicator were added. The solution was finally titrated with 0.01M ferrous ammonium sulphate solution until colour changed to blue then to a green end-point.

% Carbon in sample was estimated as:

$$\%\ \text{C in compost sample} = \frac{2.394(1.724 - \text{Titre Value} \times 0.333)}{\text{wt}}$$

Where, wt = Weight of sample (g)

0.333 = Correction factor

1.724 = Constant

3.6.3 Heavy metals and hazardous elements

A spectrophotometric method was used to analyse the heavy metals and hazardous elements of concern which include Cd, Cu, Pb, Zn, Mn, and Fe. The content of the heavy metals were measured in a digest obtained by treating samples with an acid mixture made from concentrated nitric acid, concentrated sulphuric acid, and concentrated perchloric acid.

A 1.0 g of compost sample was weighed into a 12 ml Erlenmeyer flask which has been previously washed with acid and distilled water. Five (5) ml of Ternary mixture (20 ml $HClO_4$: 500 ml HNO_3: 50 ml H_2SO_4) was added under a fume hood after which contents were mixed and heated gently at low to medium temperature on a hot plate under a perchloric acid fume hood. Heating continued until dense white fumes of sulphuric acid appeared.

The heated content was then allowed to cool, before adding 40-50 ml of distilled water and filtered completely into a 100 ml volumetric flask. Distilled water was added to the 100 ml mark. The solution was stored for heavy metal determination using the Atomic Absorption Spectrophotometer (AAS).

$$\%\ \text{Heavy Metal in compost sample} = \frac{\text{AAS reading} \times v \times 100}{\text{wt} \times 1000000}$$

Where, v = final volume of the digestion

wt = weight of the sample taken in grams

3.7 Determination of NH_4^+– N and NO_3^- – N

These were analysed by the extraction method (Keener *et. al.*, 2000).

Five (5) ml of the boric acid solution was added to a 50 ml conical flask. A flask was placed under the condenser of the steam distillation plant so that the end or tip of the condenser was about 40 cm above the surface of the boric indicator solution. An aliquot of 10 ml of the extract was pipetted into the distillation flask in addition to 0.2 g (scoop) of ignited (and cool) magnesium oxide (MgO).

The flask was attached to the distillation apparatus using spiral springs. Distillation was started by closing the stopcock on the steam bypass tube. When the distillate reached the 30 ml mark on the receiver conical flask, distillation was stopped by opening the stopcock on the steam bypass tube.

The ammonium-N content in the distillate was determined by titrating 0.002N H_2SO_4 or 0.01 MHCl placed in a micro-burette. After distilling NH_4^+ –N from the sample extract in the above procedure, the stopper was removed from the side arm of the distilling flask and 0.2 g of Devarda's alloy was added to the flask using a dry powder funnel.

The stopper was replaced immediately into the neck of the side arm, and the NO_3^- - N was distilled in fresh boric acid. The NO_3^- –N is converted to NH_4^+ and trapped in the conical flask and this ammonium is then estimated by titration with 0.002 N H_2SO_4 or 0.01 M HCl.

1. The concentration of $NH_4^+ - N$ or $NO_3^- - N$ in the compost or soil sample, expressed in mg N/kg is calculated as follows:

$$NH_4 - N\left(^{mg}/_{kg}\right) \text{ in compost sample } = \frac{MHCl \times 18 \times v \times 1000}{al \times wt}$$

v = final volume of the digestion

wt = weight of the sample taken in grams

al = aliquot of the solution

M= Molarity of HCl

18= Molar mass of H_2O

3.8 Germination test

A modified phytotoxicity test described by Zucconi *et al*., (1981) was used to test the maturity of the composts. Seeds of four (4) crops; tomatoes, sweet pepper, cucumber and watermelon were used for the germination test.

The media used for the germination bioassay comprised a mixture of compost and de-ionised water. For each treatment, 50 g of softwood sawdust compost (SSC) and hardwood sawdust compost (HSC) were mixed with 100 ml de-ionised water separately. The compost-water mixture was shaken for 6 h, and centrifuged at 8000 rpm for 20 min at 20 °C. After centrifugation, the supernatant was diluted with de-ionised water to yield 25 - 100% supernatant (compost extract).

The seeds were wetted for 12 - 14 hours prior to the initiation of the experiments to accelerate germination. Seeds were sown on a Whatman filter paper placed inside a sterilised, disposable Petri dish. Each dish received 5 ml of the appropriate treatment

extract, whereas the controls received 5 ml of de-ionised water.

The filter paper was wetted with 9 ml of 1:10 compost/water extract and 20 seeds each of tomato, sweet pepper, cucumber and water melon were placed on the paper. The petri dishes were arranged in a completely randomised block design with 20 seeds per treatment.

The petri dishes were sealed with parafin to minimize water loss but ensured adequate penetration of air and kept in a dark room for seven days at room temperature. The number of germinated seeds for each treatment were counted and recorded daily for a period of seven days.

3.9 Data analysis

The data collected were subjected to the Analysis of Variance (ANOVA) to determine the level significance of variability within the data for the various parameters. Duncan's multiple range test was used to determine differences among means.

Statsgraphics Centurion software (version 16.1) was used for statistical analysis and Microsoft Excel Software (2010 edition) for graphing of data.

CHAPTER FOUR

4.0 Results

4.1 Variation in temperature of softwood and hardwood sawdust composts

Temperature of softwood and hardwood compost heaps increased rapidly during the first three weeks but decreased steadily in subsequent weeks (Fig. 4.1). With regards to softwood sawdust compost (SSC), temperature increased from 41.57 ℃ in week one to a highest value of 56.0 ℃ at week three but decreased from the peak value to 34.86 ℃ on week 12.

Similarly, from an initial value of 35.71 ℃ in week one, temperature of hardwood compost sawdust (HSC) increased to a maximum value of 60.29 ℃ at week four but dropped steadily, taping down to 43.0 ℃ at the end of week 12. Significant variation ($p \leq 0.05$) in the average weekly temperature was recorded during the composting period.

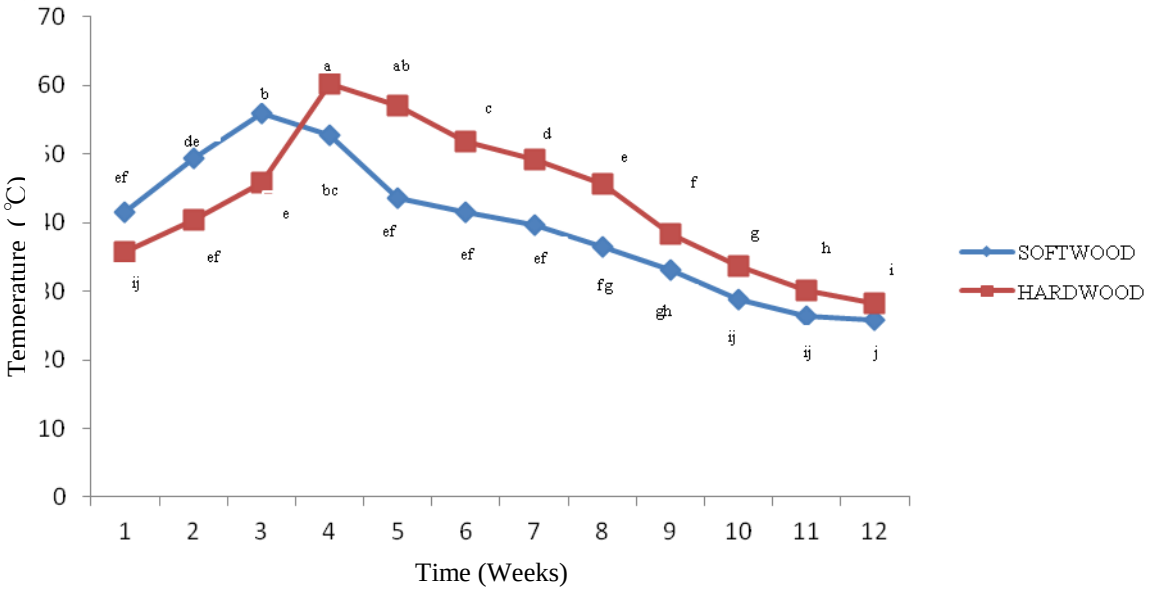

Fig.4.1. Time course of temperature for hardwood and softwood sawdust compost

Points with same alphabets are not significantly different from each other according to Duncan's multiple range test.

4.2 Variation in pH of softwood and hardwood sawdust composts

The values for pH in SSC heap was about 4.8 on week 2, but increased rapidly to 8.5 on week 6 after which pH decreased gradually to a value of 7.5 on week 12 (Fig. 4.2). A similar trend in the time course of pH was observed in HSC heap. However, the peak pH (8.7) in HSC heap was greater than that observed in SSC heap. Additionally, pH in HSC heap dropped gently from the peak value of about 8.7 on week 6 to about 7.7 on week 12 (Fig.4.2)

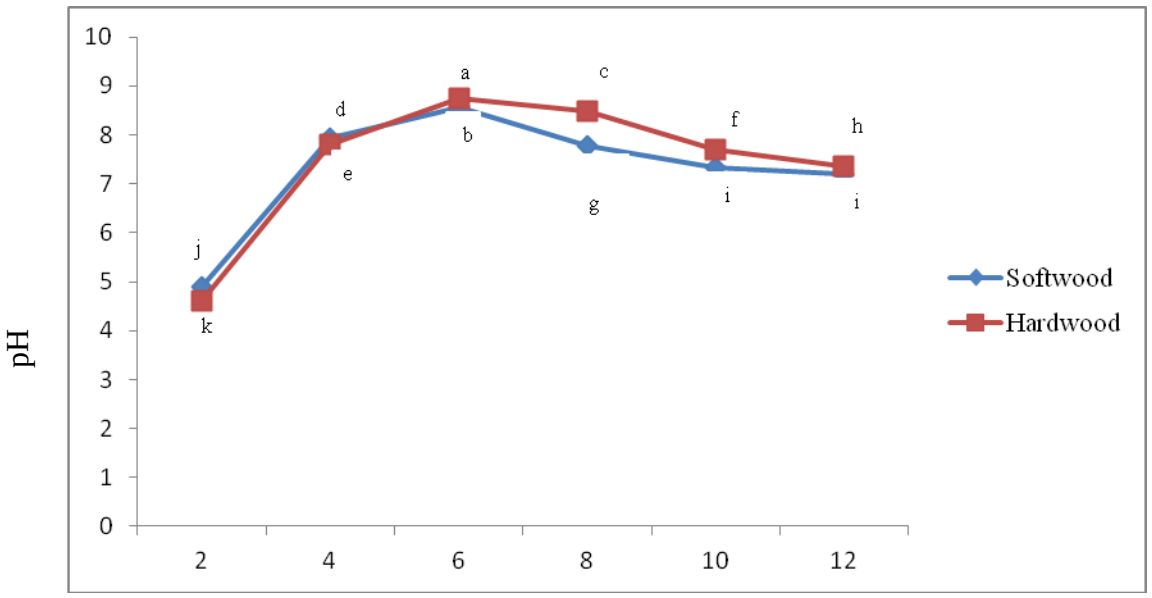

Fig. 4. 2. Time course of pH for hardwood and softwood sawdust compost

Points with same alphabets are not significantly different from each other according to Duncan's multiple range test.

4.3 Variation in moisture content of softwood and hardwood sawdust composts

Generally, there was gradual increase in moisture content after a sharp decrease from 51.39±1.85 % (SSC) and 50.98±0.44 % (HSC) at week two (2) to lowest 35.37±0.48 % (SSC) and 29.88±1.09 % (HSC) at week four (4) (Table 4.1). At the end of the period (week 12), softwood sawdust compost registered 44.46±3.58 %, while hardwood sawdust compost obtained 40.25±1.70 %.

Significant variation ($P \leq 0.05$) in moisture content was observed for both softwood sawdust compost and hardwood sawdust compost.

Table 4.1: Variation in moisture content of softwood and hardwood sawdust composts.

Week	Specimen	Moisture content(%)
2	HSC	50.98± 0.44 [a]
	SSC	**51.39± 1.85 [a]**
4	HSC	<u>29.88± 1.09</u> [h]
	SSC	35.37± 0.48 [ef]
6	HSC	30.19± 0.58 [gh]
	SSC	37.13± 1.19 [def]
8	HSC	34.03± 5.75 [fg]
	SSC	39.08± 1.33 [de]
10	HSC	46.46± 1.06 [b]
	SSC	43.39± 2.54 [bc]
12	HSC	40.25± 1.70 [cd]
	SSC	44.46± 3.58 [b]
	Mean	40.22± 7.35
	CV %	18.29 %

± sd and CV represent standard deviation and coefficient of variation respectively.Values in the same column with the same superscripts are not significantly different ($P < 0.05$) according to Duncan's Multiple range test. Highest and lowest values are **bolded** and <u>underlined</u> respectively.

SSC = Softwood sawdust compost HSC = Hardwood sawdust compost

4.4 Variation in NH_4^+ and NO_3^- of softwood and hardwood sawdust composts

Concentration of NH_4^+ and NO_3^- varied significantly, but generally values recorded for both SSC and HSC increased steadily over the period (Table 4.2).

At week 12, SSC recorded significantly higher NH_4^+content (0.153±0.002) as compared to 0.110±0.002 of HSC. Conversely, HSC gave significantly higher NO_3^- (0.121±0.002) than was recorded by SSC (0.107±0.006).

Table 4.2 Variation in NH_4^+ and NO_3^- softwood and hardwood sawdust composts

Week	Specimen	NH_4^+ (%)	NO_3^- (%)
2	SSC	0.013±0.005 [g]	0.011±0.001 [i]
	HSC	0.045±0.002 [f]	0.064±0.003 [f]
4	SSC	0.063±0.001 [e]	0.012±0.001 [i]
	HSC	0.083±0.003 [d]	0.074±0.003 [e]
6	SSC	0.064±0.009 [e]	0.031±0.002 [h]
	HSC	0.010±0.005 [g]	0.080±0.002 [d]
8	SSC	0.081±0.001 [d]	0.041±0.007 [g]
	HSC	0.084±0.003 [d]	0.085±0.001 [c]
10	SSC	0.086±0.001 [d]	0.041±0.001 [g]
	HSC	0.092±0.006 [c]	0.094±0.005 [b]
12	**SSC**	**0.153±0.002 [a]**	0.107±0.006 [c]
	HSC	0.110±0.002 [b]	**0.121±0.002 [a]**
Mean		0.071±0.034	0.062±0.002
CV %		47.26%	54.16 %

± sd and CV represent standard deviation and coefficient of variation respectively.

Values in the same column with the same superscripts are not significantly different ($P < 0.05$) according to Duncan's Multiple range test. Highest and smallest values are **bolded** and underlined respectively.

SSC = Softwood sawdust compost HSC = Hardwood sawdust compost

4.5 Variation in C: N ratios of softwood and of hardwood sawdust composts

Carbon and nitrogen contents and C:N ratios of SSC and HSC for a period of twelve weeks is shown in Table 4.3. Significant variation ($P \leq 0.05$) was recorded for all the parameters for both treatments (Appendix 6.4). From highest of 1.71±0.002% at week two, nitrogen content of SSC decreased sharply to 1.63±0.029% at week four, but

dropped steadily in subsequent weeks to reach lowest of 1.25±0.001% at week 12. Similarly, nitrogen content of HSC decreased sharply from week four (1.66±0.053%) to week six (1.35±0.002%), but reduced gradually during the period with highest (1.89±0.002%) and lowest (1.10±0.306%) values recorded at week two and week 12 respectively.

Carbon content of both treatments declined steadily during the period with highest of 35.68±0.16% (HSC) and 34.58±0.01% (SSC) at week two and lowest of 21.87±1.24% and 18.63±0.02% recorded for HSC and SSC respectively at week 12. Correspondingly, from week two to week 8, C: N ratio of SSC decreased steadily, but increased gradually to 14.90±0.55 at weeks 12. Conversely, C:N ratio of HSC increased steadily from week two to week six, but decreased subsequently to reach 19.88±0.10 at week 12.

Table 4.3: Variation in C:N ratio of hardwood and softwood sawdust composts

Week	Specimen	% N	% C	C : N Ratio
2	HSC	1.71±0.002 ^{b}	**35.68±0.16** ^{a}	20.87±0.02 ^{ab}
	SSC	**1.89±0.002** ^{a}	34.58±0.01 ^{c}	18.30±0.03 ^{e}
4	HSC	1.66±0.053 ^{c}	33.84±0.05 ^{b}	20.39±0.08 ^{b}
	SSC	1.63±0.029 ^{bc}	26.87±1.16 ^{e}	16.48±0.03 ^{f}
6	HSC	1.35±0.002 ^{c}	28.32±0.02 ^{d}	**21.00±0.04** ^{a}
	SSC	1.59±0.006 ^{bc}	22.38±0.51 ^{g}	14.08±0.04 ^{gh}
8	HSC	1.27±0.002 ^{c}	24.23±0.03 ^{f}	19.08±0.17 ^{d}
	SSC	1.55±0.004 ^{bc}	21.02±0.01 ^{h}	13.56±0.02 ^{h}
10	HSC	1.15±0.001 ^{d}	22.14±0.05 ^{f}	19.25±0.03 ^{d}
	SSC	1.32±0.001 ^{d}	19.03±0.03 ^{i}	14.42±0.04 ^{gh}
12	HSC	1.10±0.306 ^{e}	21.87±1.24 ^{h}	19.88±0.10 ^{c}
	SSC	1.25±0.001 ^{d}	18.63±0.02 ^{i}	14.90±0.55 ^{g}

Mean	1.48±0.277	25.80±5.47	18.28±4.50
CV %	18.72 %	21.22 %	24.59 %

± sd and CV represent standard deviation and coefficient of variation respectively.

Values in the same column with the same superscripts are not significantly different ($P < 0.05$) according to Duncan's Multiple range test. Highest and smallest values are **bolded** and underlined respectively.

SSC = Softwood sawdust compost HSC = Hardwood sawdust compost

4.6 Elemental composition of hardwood and softwood sawdust composts

Significant variation ($p \leq 0.05$) (Appendix 6.6) in concentration of all assayed elements was recorded during the composting period in this study (Table 4.4). Nevertheless, concentration of phosphorus (P) and potassium (K) of both SSC and HSC increased, while those of the heavy metals zinc (Zn), lead (Pb), manganese (Mn), iron (Fe), copper (Cu) and cadmium (Cd) generally decreased over the period.

At the end of the period (week 12), SSC gave significantly lower values for P (0.20±0.02), K (0.32±0.003) and Zn (0.0000±0.00) than was recorded by HSC, 0.23±0.020, 0.34±0.02 and 0.0001±0.00 for P, K and Zn respectively.

Also, at week 12, HSC registered significantly higher values, 0.0020±0.00, 0.002±0.001, 0.005±0.00 0.0007±0.00 and 0.0023±0.00 than those obtained for SSC, 0.0007±0.00, 0.0017±0.00, 0.002±0.00, 0.00004±0.00 and 0.0017±0.00 with regards regards to Pb, Mn, Fe, Cu and Cd respectively.

Table 4.4: Concentration of elements composition of hardwood and softwood sawdust composts

Week	Specimen	P (%)	K (%)	Zn (%)	Pb (%)	Mn (%)	Fe (%)	Cu (%)	Cd (%)
2	HSC	0.65±0.020 ^{b}	0.55±0.02 ^{c}	0.0017±0.06 ^{bc}	**0.1832±0.005** ^{a}	**0.0735±0.001** ^{a}	0.027±0.00 ^{a}	**0.00200±0.03** ^{a}	0.0647±0.005 ^{a}
	SSC	**0.70±0.001** ^{a}	**0.89±0.002** ^{a}	**0.0025±0.001** ^{a}	0.0039±0.002 ^{c}	0.0019±0.001 ^{bc}	0.054±0.01 ^{b}	0.0039±0.001 ^{a}	**0.0655±0.001** ^{a}
4	HSC	0.56±0.010 ^{d}	0.55±0.02 ^{c}	0.0016±0.06 ^{bcd}	0.1787±0.001 ^{b}	0.0062±0.070 ^{b}	0.0196±0.04 ^{b}	0.00123±0.06 ^{b}	0.0041±0.002 ^{b}
	SSC	0.60±0.040 ^{c}	0.88±0.001 ^{a}	0.0024±0.001 ^{b}	0.0034±0.002 ^{c}	0.0017±0.00 ^{d}	0.032±0.01 ^{c}	0.0034±0.001 ^{a}	0.0030±0.001 ^{bc}
6	HSC	0.50±0.040 ^{e}	0.52±0.01 ^{c}	0.0010±0.01 ^{bcd}	0.0030±0.005 ^{c}	0.0022±0.02 ^{bc}	0.0170±0.01 ^{d}	0.00025±0.04 ^{c}	0.0023±0.001 ^{bc}
	SSC	0.57±0.002 ^{d}	0.59±.0001 ^{b}	0.0024±0.001 ^{b}	0.0033±0.002 ^{c}	0.0016±0.001 ^{bc}	0.019±0.01 ^{e}	0.0033±0.002 ^{a}	0.0017±0.00 ^{bc}
8	HSC	0.33±0.010 ^{h}	0.45±0.06 ^{d}	0.0004±0.06 ^{cd}	0.0027±0.001 ^{c}	0.0020±0.002 ^{bc}	0.007±0.02 ^{g}	0.00014±0.02 ^{bc}	0.0013±0.006 ^{bc}
	SSC	0.55±0.002 ^{d}	0.55±0.001 ^{c}	0.0024±0.001 ^{bc}	0.0031±0.001 ^{c}	0.0016±0.001 ^{bc}	0.013±0.02 ^{f}	0.0031±0.002 ^{ab}	0.0017.001 ^{bc}
10	HSC	0.30±0.040 ^{i}	0.36±0.02 ^{g}	0.0004±0.01 ^{cd}	0.0027±0.001 ^{c}	0.0020±0.002 ^{c}	0.007±0.01 ^{g}	0.00011±0.01 ^{bc}	0.0009±0.001 ^{c}
	SSC	0.33±0.001 ^{h}	0.41±0.001 ^{f}	0.0004±0.001 ^{cd}	0.0013±0.001 ^{c}	0.0014±0.001 ^{bc}	0.003±0.001 ^{hi}	0.0013±0.001 ^{bc}	0.0016±0.002 ^{bc}
12	HSC	0.23±0.020 ^{j}	0.34±0.02 ^{h}	0.0001±0.00 ^{d}	0.0020±0.00 ^{d}	<u>0.0002±0.004</u> ^{c}	0.005±0.00 ^{a}	<u>0.00004±0.00</u> ^{d}	0.00016±0.002 ^{bc}
	SSC	<u>0.20±0.001</u> ^{k}	<u>0.32±0.003</u> ^{g}	<u>0.0000±0.00</u> ^{d}	<u>0.0007±0.00</u> ^{d}	0.0013±0.002 ^{bc}	<u>0.002±0.001</u> ^{i}	0.0007±0.002 ^{c}	<u>0.0001±0.002</u> ^{c}
	Mean	0.43±0.16	0.52±0.03	0.001±0.09	0.062±0.08	0.014±0.03	0.043±0.07	0.00063±0.01	0.0124±0.02
	CV %	37.08 %	19.24 %	107.486 %	139.49 %	196.738 %	163.405 %	228.6 %	195.719 %

± sd and CV represent standard deviation and coefficient of variation respectively. Values in the same column with the same superscripts are not significantly different ($P < 0.05$) according to Duncan's Multiple range test. Highest and smallest values are **bolded** and <u>underlined</u> respectively.

SSC = Softwood sawdust compost HSC = Hardwood sawdust compost

4.7 Concentration of pathogens in hardwood and softwood sawdust composts

Pathogenic levels recorded for both SSC and HSC at the end of twelve weeks of composting were generally low for Table 4.5a. Concentration of the various pathogens in both SSC and HSC decreased significantly over the period. At week 12, faecal coliform was not detectable in both compost heaps, while values for total viable count(TVC), total coliform count(TCC) and *Salmonella* counts of both composts were less than 10^6 (Table 4.5 a).

Table 4.5a: Concentration of pathogens in hardwood and softwood sawdust composts.

	HARDWOOD SAWDUST COMPOST				SOFTWOOD SAWDUST COMPOST			
Week	**TVC**	**TCC**	**FCC**	***Salmonella* count**	**TVC**	**TCC**	**FCC**	***Salmonella* count**
2	34000000	14000000	12000000	100000	35000000	16000000	10000000	300000
4	30000000	9000000	100000	500000	31000000	10000000	500000	600000
6	6000000	700000	100000	21000	3200000	500000	0	110000
8	500000	1000	0	0	200000	300000	0	0
10	16000	0	0	0	138000	0	0	0
12	1000	0	0	0	12000	0	0	0
MEAN	108.65*	2.48*	2.02*	0.13*	92.87*	1.60*	0.18*	0.15*
STEV	143.02 *	56.46*	4.89*	1.97*	102.80*	2.75*	0.25*	0.21*
CV%	131.6	227.4	242.5	147.3	110.7	171.9	135.5	136.4

* = 10^6 STEV and CV represent standard deviation and coefficient of variation respectively.
TVC = Total viable count TCC = Total coliform count FCC = Faecal coliform count

Similarly, concentration of helminth eggs in both SSC and HSC, with the exception of *Coccidia oocyst* and Cyst of amoeba generally decreased over the period (Table 4.5b). At the end of the composting period (week 12), *Ascaris spp.*, *Strongyle spp.*, and *Escherichia histolytica* were not detected in both SSC and HSC. However, SSC recorded a count of 27 and 34 for *Coccidia oocysts* and Cysts of amoeba, while HSC gave 13 and 42 respectively at the end of the composting period.

Table 4.5b: Number of Helminth eggs in softwood and hardwood sawdust composts

Week	Specimen	*Coccidia oocyst*/g	*Ascaris spp*/g	Strongyle/g	*Escherichia histolytica*/g	Cyst of amoeba/g
2	SW	3	0	3	0	5
	HW	0	0	2	0	9
4	SW	4	0	0	20	8
	HW	18	2	0	2	10
6	SW	3	1	0	0	27
	HW	4	0	1	2	23
8	SW	2	0	0	7	19
	HW	4	0	0	5	9
10	SW	2	0	0	0	37
	HW	18	0	0	0	32
12	SW	27	0	0	0	34
	HW	13	0	0	0	42

SSC = Softwood sawdust compost HSC = Hardwood sawdust compost

4.9 Germination test for softwood and hardwood sawdust composts

The results of germination test for different concentrations of softwood sawdust compost (SSC) and hardwood sawdust compost (HSC) for a period of seven days are shown on Table 4.6. Generally, the number of seeds that germinated for all the crops tested increased steadily over the period. Significant variation was also observed in the number of germinated seeds for SSC and HSC.

At 100 % concentration, seeds treated with SSC recorded significantly higher number of germinated seeds of 17.00±0.00, 9.67±0.58 and 7.67±1.15 for cucumber (Cu), Sweet pepper (Sp) and tomato (To) respectively than HSC, 15.33±0.00 (Cu), 8.67±0.58 (Sp) and 6.00±1.00 (To). However, HSC gave significantly higher value of

(17.00±1.15) than SSC (14.02±1.05) with respect to watermelon (Wm) at the end of the period (Day 7).

Also at 50% concentration of HSC, the number of treated seeds that germinated were 8.33±1.53 (SP), 7.33±1.00 (To), 13.33±0.67 (Cu) and 15.67±2.52 at the end of day 7. For the 50% concentration of SSC, the treated seeds that geminated were 8.67± 0.58 (SP), 8.67±1.15 (To), 15.33±0.60 (Cu) and 15.00±0.00 (Wm). Furthermore, water melon seeds treated with 50% concentration of HSC had comparatively higher number of germinated seeds (15.67±2.52) than that of SSC at the end of the seventh day.

There was no significant difference between the highest number of seeds of cucumber and water melon that germinated with respects to treatments with 25% concentration of both SSC and HSC. Softwood sawdust compost (SSC) scored significantly higher values for cucumber (Cu), sweet pepper (Sp) and water melon (Wm), while HSC obtained higher value for tomato (To) at day 7, with respect to the 25% concentration of the treatment.

Over the period, highest values recorded for the control (0 %), were 18.00±0.00, 9.00±2.00, 8.67±1.15 and 17.02±1.05 for cucumber, sweet potato, tomato and water melon respectively.

Table 4.6: Germination test for Softwood and hardwood sawdust composts.

Day	Specimen	100 %				50 %				25 %				0 % (Control)			
		Cu	Sp	To	Wm	Cu	Sp	To	Wm	Cu	Sp	To	Wm	Cu	Sp	To	Wm
1	HSC	0.00±0.00 ^{j}	0.00±0.00 ^{g}	0.00±0.00 ^{f}	0.00±0.00 ^{j}	0.00±0.00 ^{i}	0.00±0.00 ^{h}	0.00±0.00 ^{fg}	0.00±0.00 ^{j}	0.00±0.00 ^{j}	0.00±0.00 ^{f}	0.00±0.00 ^{h}	0.00±0.00 ^{f}	0.00±0.00 ^{f}	0.00±0.00 ^{d}	0.00±0.00 ^{d}	0.00±0.00 ^{de}
	SSC	0.00±0.00 ^{j}	0.00±0.00 ^{g}	0.00±0.00 ^{f}	0.00±0.00 ^{j}	0.00±0.00 ^{i}	0.00±0.00 ^{h}	0.00±0.00 ^{fg}	0.00±0.00 ^{j}	0.00±0.00 ^{j}	0.00±0.00 ^{f}	0.00±0.00 ^{h}	0.00±0.00 ^{f}				
2	HSC	3.00±0.00 ^{hi}	0.00±0.00 ^{g}	0.00±0.00 ^{f}	0.00±0.00 ^{j}	5.33±0.58 ^{g}	0.00±0.00 ^{h}	0.00±0.00 ^{fg}	0.00±0.00 ^{j}	1.00±0.00 ^{ij}	0.00±0.00 ^{f}	0.33±0.58 ^{h}	0.00±0.00 ^{f}	0.00±0.00 ^{f}	0.00±0.00.00 ^{d}	0.00±0.00 ^{d}	0.00±0.00 ^{de}
	SSC	4.33±0.58 ^{h}	1.33±2.31 ^{fg}	0.33±0.58 ^{ef}	0.33±0.58 ^{j}	4.00±1.00 ^{g}	0.33±0.58 ^{h}	0.00±0.00 ^{fg}	0.00±0.00 ^{j}	1.00±0.00 ^{ij}	0.33±0.58 ^{f}	0.00±0.00 ^{h}	0.00±0.00 ^{f}				
3	HSC	7.33±0.55 ^{f}	0.33±0.58 ^{g}	0.67±1.15 ^{ef}	7.00±0.58 ^{g}	7.00±0.52 ^{f}	2.33±2.08 ^{ef}	1.00±0.00 ^{f}	5.00±0.00 ^{g}	4.00±1.00 ^{g}	1.33±0.58 ^{ef}	1.67±1.53 ^{gh}	0.67±1.15 ^{f}	2.67±0.58 ^{e}	0.67±0.58 ^{cd}	0.00±0.00 ^{d}	1.00±0.58 ^{d}
	SSC	8.67±0.25 ^{ef}	4.00±2.00 ^{e}	1.00±1.00 ^{e}	2.70±0.00 ^{i}	9.67±1.53 ^{e}	1.33±2.31 ^{fg}	2.00±0.00 ^{ef}	2.00±1.73 ^{i}	6.33±0.58 ^{ef}	2.67±1.15 ^{e}	2.67±2.31 ^{g}	2.00±0.00 ^{ef}				
4	HSC	10.00±0.00 ^{de}	2.33±2.08 ^{f}	2.67±2.52 ^{de}	8.00±0.00 ^{fg}	9.67±0.50 ^{e}	4.67±4.51 ^{d}	3.00±0.00 ^{e}	10.00±4.36 ^{de}	6.33±2.89 ^{ef}	2.330.58 ^{e}	5.33±2.08 ^{d}	0.67±0.58 ^{d}	5.00±0.00 ^{c}	1.33±0.58 ^{c}	1.67±0.58 ^{c}	2.33±1.00 ^{cd}
	SSC	11.33±0.58 ^{d}	4.67±4.51 ^{e}	2.67±1.15 ^{de}	4.33±1.15 ^{h}	10.67±0.52 ^{de}	4.00±2.00 ^{d}	5.00±0.00 ^{d}	5.67±3.21 ^{g}	8.67±3.51 ^{de}	4.00±0.00 ^{d}	4.00±1.00 ^{ef}	4.33±0.58 ^{de}				
5	HSC	11.67±0.90 ^{d}	4.67±1.15 ^{e}	5.33±1.15 ^{bc}	10.67±0.00 ^{e}	11.00±1.00 ^{d}	6.00±2.00 ^{c}	5.00±0.00 ^{d}	13.00±1.73 ^{bc}	9.00±0.00 ^{d}	3.67±0.58 ^{de}	7.00±1.73 ^{d}	2.00±1.00 ^{ef}	6.33±0.58 ^{bc}	2.33±0.58 ^{bc}	3.00±0.00 ^{b}	4.00±1.00 ^{b}
	SSC	12.33±0.76 ^{cd}	6.00±2.00 ^{d}	3.33±1.15 ^{cd}	7.33±0.00 ^{g}	12.67±0.58 ^{cd}	4.67±1.15 ^{d}	6.33±0.58 ^{c}	10.00±2.65 ^{de}	10.33±0.58 ^{cd}	4.67±1.15 ^{d}	8.33±2.08 ^{cd}	7.00±1.00 ^{c}				
6	HSC	13.67±0.40 ^{c}	7.33±0.58 ^{c}	5.33±1.53 ^{bc}	15.00±0.00 ^{b}	13.00±0.00 ^{b}	7.33±0.58 ^{bc}	7.00±1.15 ^{b}	15.00±2.52 ^{a}	10.00±0.00 ^{cd}	5.67±0.00 ^{cd}	10.33±2.08 ^{b}	2.00±1.00 ^{ef}	7.67±0.58 ^{b}	3.33±0.58 ^{ab}	3.33±0.58 ^{ab}	4.67±0.00 ^{ab}
	SSC	14.67±.70 ^{bc}	7.67±2.08 ^{c}	6.67±1.15 ^{b}	10.66±0.58 ^{e}	14.33±0.58 ^{ab}	7.67±2.08 ^{b}	7.33±1.53 ^{b}	13.33±2.89 ^{bc}	14.33±0.58 ^{b}	5.67±0.58 ^{cd}	9.33±1.53 ^{c}	9.67±1.53 ^{b}				
7	HSC	15.33±0.58 ^{b}	8.67±0.58 ^{b}	6.00±1.00 ^{b}	**17.00±1.15** ^{a}	13.33±0.67 ^{b}	8.33±1.53 ^{a}	7.33±1.00 ^{b}	**15.67±2.52** ^{a}	10.00±0.00 ^{cd}	7.33±1.53 ^{b}	**12.33±2.52** ^{a}	3.00±1.00 ^{e}	**8.00±0.00** ^{a}	**4.33±3.21** ^{a}	**4.33±0.58** ^{a}	**5.00±1.73** ^{a}
	SSC	**17.00±0.00** ^{a}	**9.67±0.58** ^{a}	**7.67±1.15** ^{a}	14.02±1.05 ^{c}	**15.33±0.60** ^{a}	**8.67±0.58** ^{a}	**8.67±1.15** ^{a}	15.00±0.00 ^{a}	**15.33±0.58** ^{a}	**8.00±2.00** ^{a}	10.67±1.53 ^{b}	**10.67±0.58** ^{a}				
Mean		6.76± 5.31	1.79±1.69	5.14±4.58	1.71±1.80	7.36±6.32	4.03±3.66	3.05±2.85	3.11±3.55	12.10±7.45	4.02±3.66	1.47±1.45	7.67±6.62	10.33±7.02	3.07±2.64	3.62±3.12	7.14±6.21
CV %		78.51%	92.63%	89.95%	104.89%	85.85%	90.94%	93.62%	114.57%	61.62%	5.97%	98.3%	86.36%	67.92 %	85.90%	86.08%	86.89%

TO = Tomatoes SP = Sweet pepper CU = Cucumber WM = Watermelon

±sd = Standard deviation CV = Coefficient of variation. **Bolded** and underlined values represent highest number of seed that germinated for each crop. Means in same column with same alphabets are not significantly different according to Duncan's multiple range test.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Variation in temperature of softwood and hardwood sawdust composts

Time course of temperature serves as an important indicator of microbial activity and thus, the rate of degradation of substrate material during composting process. High temperatures occur during periods of increased microbial activities (Leton and Stentiford, 1990). Variation in temperature of SSC and HSC in this study is characteristic of composting process which typically involves an initial increase in temperature to a maximum, followed by a steady decrease (Stromberger *et al.*, 2011).

Significantly higher temperature maintained for longer period was recorded for both SSC and HSC relative to those reported by Prempeh. (2010), who studied co-composting of a mixture of hardwood and softwood sawdust with food waste as well as Obodai *et al*. (2010), who used only softwood sawdust (*Triplochiton scleroxylon*) with amendment from food waste. This indicates that better and more rapid decomposition of the sawdust was achieved in this study, probably due to the contribution of nitrogen from the mucuna leaves.

Chemical composition of the organic substrates could have also accounted for the different rates of decomposition (Litterick *et al., 2004*). Cellulose, for example, may be readily attacked when in a pure state, but if present in intimate relation to lignin or resinous materials (as found in mixtures of sawdust from hardwood and softwood species), it may be decomposed slowly. Typically, HSC contain more complex compounds such as cellulose and lignin than SSC, hence decomposition rates of HSC could be expected to be relatively slower.

As indicated by Keener *et al*. (2000), the decline in temperature at the end of the period could suggest that most of the degradable components of both SSC and HSC had been converted into stable compounds hence, both materials were well composted.

5.2 Variation in pH of softwood and hardwood sawdust composts

Optimum pH for thermophilic microorganisms was maintained for a relatively longer period for both materials treated in this study as compared to those achieved by earlier authors who also worked on composting of sawdust in Ghana (Costello and Sullivan, 2011; Prempeh, 2010; Baffour-Asare, 2009). This supports the fact that better decomposition of the organic material in the sawdust was achieved in this study than was recorded by the earlier workers since thermophilic microorganisms decompose complex compounds such as cellulose and hemicelluloses which are typically found in sawdust.

Though suitable pH for thermophiles lasted longer for HSC than SSC, this could not account for better decomposition of the organic material of HSC. Thus, the high pH of HSC was probably due to release of ammonia during the thermophilic phase which is known to increase pH of the compost. Loss of nitrogen through volatilisation of ammonia reduces the agronomic value of compost and also contributes to greenhouse gas emissions (Hao *et al*., 2004). Nonetheless pH of the final product of SSC and HSC was within acceptable range (6 – 8) for good composts (Smith and Doran, 1996).

5.3 Variation in moisture content of softwood and hardwood sawdust composts

Though moisture was well managed during the composting process, moisture contents of SSC and HSC varied significantly during the period. This is evident from the sharp decrease in moisture content of SSC in the mesophilic phase. A similar pattern during the thermophilic phase was observed for HSC. As suggested by Baffour-Asare, (2009), utilisation of water in the compost pile due to increase in microbial activities and evaporation of water in the respective phases may have resulted in this outcome.

Epstein (1997) and Sesay, (1997) recommended optimum moisture content in compost to be 40 – 60 % on dry mass basis for effective decomposition of organic materials. Beyond this range, microbial activities of aerobic microorganisms decrease considerably, since too dry or water-logged conditions result in decreased supply of oxygen. Moisture content is also important because it provides a medium for transporting dissolved nutrients needed for metabolic and physiological activities of microorganisms (McCartney and Tingley, 1998).

The significantly higher moisture content ($p < 0.05$) of final product of SSC as compared to that of HSC could be due to the fact that SSC absorbed more water during the decomposition process, hence resulted in rapid decomposition of SSC. Nevertheless moisture contents of the final composts for HSC and SSC were within acceptable limits as suggested by Sesay (1997).

5.4 Variation in Carbon, Nitrogen and Carbon/Nitrogen ratio of softwood and hardwood sawdust composts

Organic-C and organic-N contents of final compost of both HSC and SSC studied were significantly reduced compared to those recorded by (Prempeh, 2010; Baffour-Asare, 2009; Kalamdhad and Kazmi, 2009; Huang *et al*., 2004). This affirms that better decomposition was achieved in this study than were reported by the earlier researchers.

Variations in carbon and nitrogen contents in this study also supports the fact that better decomposition was achieved for SSC compared to HSC. These could be due to the high lignin and cellulose contents of HSC. Studies indicate that the extent of decomposition achieved during composting of sawdust is directly related to the cellulose and lignin contents of the wood species utilised. Hardwood contains up to 40% cellulose compared softwood species (5%) (Brown *et al*., 1998).

However, final compost of SSC recorded significantly higher amount of plant-available nutrients than HSC. This suggests that, a significant percentage of organic material of HSC broke down but was lost, probably through volatilisation of ammonia which is associated with higher temperatures and prolonged thermophilic phase (Campbell and Reece, 2002), while those of SSC were converted into plant-available inorganic forms. Moreover, though final product of HSC contains significantly higher amount of nitrate than SSC, ammonium ion (NH_4^+-N) which is the preferred form of nitrogen by most crops was significantly higher in SSC.

At the end of the composting process, the concentration of organic-N left in both HSC and SSC were within the range, 0.4% − 3.5% for good compost (Gotass,1956). This is

very critical since this nitrogen form is unavailable to crops, but too high or too low amount in compost products can lead to phytotoxicity effect on crops due to release of ammonia and organic acids by microorganisms in the soil.

5.5 Elemental composition of softwood and hardwood sawdust compost Potassium and Phosphorous

Organic phosphorus (P) and potassium (K) are used by bacteria and fungi during decomposition of organic matter and in the process transform them into inorganic forms (PO_4^{3-}) which can be absorbed by plants (Campbell and Reece, 2002). Consequently, the rate at which these nutrients are converted helps to estimate the extent of decomposition achieved during composting process as well as quality of the final composts with regards to plant-available nutrients.

Concentrations of the organic P and K recorded in the final composts of both SSC and HSC were significantly lower than was reported by Prempeh (2010), Obodai *et al.* (2010) and Baffour Asare (2009), who also studied sawdust compost amended with food waste in Ghana. This is an indication that both amendments investigated in this study remarkably increased minerilisation of the organic P and K in the sawdust into inorganic plant-available forms (PO_4^{3-}, KOH and K_2O), than was achieved by other workers (Prempeh, 2010; Baffour Asare, 2009).

This notwithstanding, organic-P content in the final compost of HSC was significantly higher than was registered by SSC. On the other hand SSC obtained significantly high organic K as compared to that of HSC at the end of the period.

5.6 Concentration of Heavy Metals in softwood and hardwood sawdust composts

Beside sanitary quality, compost used in agriculture should also meet ecological standards preferably low concentration of heavy metals. Due to their phytotoxic effect on crops and other organisms through bioaccumulation at higher trophic levels in the food chain, knowledge of the amount of toxic elements (heavy metals) in compost is very important from ecological point of view.

Concentrations of the heavy metals (Zn, Pb, Cu and Cd) in both materials treated in this study were significantly lower than those found by (Prempeh, 2010), who investigated levels of these elements in sawdust amended with food waste and also within acceptable limits. This suggests that the amendment of the sawdust used this study possibly contributed to binding of the heavy elements during the composting process as indicated by Barker and Bryson (2002), hence their considerable reduction. From ecological point of view, this is very crucial since it will prevent contamination of water bodies or from being absorbed by plants.

Since the primary objective for applying compost to the soil is to supply essential nutrients to enhance the growth of crops, it is desirable that the levels of toxic elements, particularly cadmium and lead which are not essential for plant growth were significantly reduced in order not to detract from the expected benefits from the compost.

5.7 Concentration of pathogens in softwood and hardwood sawdust compost

Concentrations of indicator organisms such as coliform bacteria help to make predictions about levels of other pathogens since they generally occur at higher levels

and are simple and safer to detect. Helminth eggs are the most resistant pathogens to extreme conditions hence if their population is significantly reduced by the composting process, it could be considered that all other pathogens have been removed as well (Feachem *et al*., 1983).

Relative to concentrations of pathogens recorded by investigators (Obodai *et al*. 2010; Prempeh, 2010; Baffour Asare, 2009), those achieved in this study were significantly lower and also within the acceptable limits as necessary for application for soil conditioning (USEPA, 1994). This is a strong indication that the final composts produced in this study would have no toxic effect to plants with respect to phytotoxicity of pathogens.

Several factors, including exhaustion of nutrients from the organic matter and longer thermophilic phase in consonance with observation by Ostrem (2004) and Golueke (1983) could have accounted for the low levels of pathogens recorded in this study. Increase in temperature during decomposition process characteristically results in partial pasteurization of compost heaps, thus causing death of most pathogens (Epstein, 1997).

Though the highest temperature observed for SSC in this study was significantly lower than that of HSC, this could not exert any major difference in their pathogenic concentration at the end of the period. Antagonistic or indigenous organisms and proper management of the composting process could have also played unique roles in destruction of the pathogens as observed by Larsen and McCartney (2000).

5.8 Stability and maturity of softwood and hardwood sawdust composts

Being a more sensitive method for phytotoxicity assessment, outcomes of germination test are very critical in predicting plant growth response upon application of composts (Ofosu-Badu *et al.*, 2010; Baffour Asare, 2009).

The outcome of the germination bioassay reveals positive correlation between concentrations of the compost extracts and number of seeds that germinated during the period. This indicates that, final products of both amendments investigated in this study contain low levels of toxic factors such as salinity or phenolic compounds which are known to inhibit germination of seeds (Hargreaves *et al*., 2008; Hue *et al*., 1995).

It also points to the fact that HSC and SSC contain adequate levels of nutrients for crop cultivation since dilutions of the compost extracts of both SSC and HSC achieved significantly higher germination rates for all the crops treated in the study than was recorded by the control treatment.

Notwithstanding fact that seed germination generally correlated with concentration of compost extracts, germination rates of seeds treated with SSC were significantly higher than HSC. This could be attributed to the high nitrate content of HSC since accumulation of nitrate is associated with increase in EC which is known to have inhibitory effect on seed germination (Smith and Doran, 1996).

In agreement with earlier workers (Ofosu-Badu *et al.*, 2010; Ortega *et al.*, 1996), significant variation with respect to phytotoxic response among the crops used in this

study, could be attributed to differences in tolerance to phytotoxic compounds by the different species. For instance tomato (*Lycopersicon esculentum*) seeds being very sensitive to the presence of phenolic compounds in growth media (Sessay, 1997), recorded the least number of seedlings for both SSC and HSC in this study.

Contrary to the outcome of this study, Ofosu-Badu *et al.* (2010) and Sessay (1997) recorded high germination rates for tomato and attributed it to high tolerance of electrical conductivity of tomato seeds. This probably means that the inhibitory effects on seeds used in this study may be the effect of other phytotoxic factors such as organic acids produced from mineralisation of carbon which are noted during composting of carbon rich material such as sawdust (Tiquia, 2005). It also suggests that seeds of cucumber, sweet pepper and water melon are perhaps not sensitive enough to detect the phytotoxic effect of organic acids in the composts.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Co-composting of sawdust and food waste, with supplemental applications of nitrogen rich plant materials such as mucuna leaves significantly improves efficiency of degradation of both hardwood and softwood sawdust. Also amendments of sawdust with nitrogen rich materials can considerably reduce concentrations of pathogens and toxic elements in the finished products to acceptable limits for application as soil conditioner.

In addition, treatments with supplemental nitrogen can significantly increase levels of nutrients for promoting plant growth and negligible amount of phytotoxins that would have detrimental effects on plants when applied to the soil. However, treatment of SSC produce better quality compost with respect to plant-available nutrients than HSC, most probably due to loss of significant amounts of nitrogen from HSC through volatilization of ammonia.

7.0 RECOMMENDATION

Future work on composting of sawdust in Ghana should target sawdust from softwood species since the amendment of SSC produced better quality compost than HSC. Further research targeting specific wood species utilised in Ghana would help to further optimise efficiency of composting of sawdust in Ghana. Also, multi-locational field trials would help to better assess stability and maturity of the final compost produced in this study since differences in ecological factors could affect the outcomes of field trials. Thus any research in this regard is strongly recommended.

Volatilization of nitrogen in the form of ammonia from HSC could be reduced by

treatment with phosphoric acid during composting. It is also recommended that the final compost of HSC should be stored for a longer period in order to achieve better stability before it is applied to the soil.

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APPENDICES

APPENDIX 1a: A **NOVA Table for TEMPERATURE of Softwood by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2446.0	11	222.364	102.63	0.0000
Within groups	52.0	24	2.16667		
Total (Corr.)	2498.0	35			

APPENDIX 1b: **ANOVA Table for TEMPERATURE of Hardwood by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2792.08	11	253.826	142.78	0.0000
Within groups	42.6667	24	1.77778		
Total (Corr.)	2834.75	35			

APPENDIX 2a: **ANOVA Table for pH softwood by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	31.3567	5	6.27134	4723.19	0.0000
Within groups	0.0159333	12	0.00132778		
Total (Corr.)	31.3727	17			

APPENDIX 2b: **ANOVA Table for pH hardwood by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	32.1379	5	6.42758	14462.06	0.0000
Within groups	0.00533333	12	0.000444444		
Total (Corr.)	32.1433	17			

APPENDIX 4: **ANOVA Table of Moisture for ssc. and hsc. by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1763.51	11	160.319	29.66	0.0000
Within groups	129.705	24	5.40438		
Total (Corr.)	1893.22	35			

APPENDIX 5: **ANOVA Table for % C by Type of wood**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	49.284	1	49.284	1.55	0.2479
Within groups	253.854	8	31.7317		
Total (Corr.)	303.138	9			

APPENDIX 6a: **ANOVA Table for softwood C:N ratio by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	404.443	5	80.8885	29603.26	0.0000
Within groups	0.032789	12	0.00273242		
Total (Corr.)	404.475	17			

APPENDIX 6b: **ANOVA Table for C: N ratio Hardwood by week**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	402.248	5	80.4497	2977.10	0.0000
Within groups	0.324274	12	0.0270228		
Total (Corr.)	402.573	17			

APPENDIX 7: **ANOVA Table of % N for ssc. and hsc.**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.0898704	1	0.0898704	0.91	0.3692
Within groups	0.794227	8	0.0992784		
Total (Corr.)	0.884098	9			

APPENDIX 8: **ANOVA Table for % P of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.0017424	1	0.0017424	0.05	0.8351
Within groups	0.301523	8	0.0376904		
Total (Corr.)	0.303266	9			

APPENDIX 9: **ANOVA Table for % K of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.03481	1	0.03481	1.43	0.2654
Within groups	0.1942	8	0.024275		
Total (Corr.)	0.22901	9			

APPENDIX 10: **ANOVA Table for % Zn of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.00170141	1	0.00170141	1.01	0.3453
Within groups	0.0135337	8	0.00169171		
Total (Corr.)	0.0152351	9			

APPENDIX 11: **ANOVA Table for % Pb of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.00451091	1	0.00451091	1.29	0.2941
Within groups	0.0245544	7	0.00350777		
Total (Corr.)	0.0290653	8			

APPENDIX 12: **ANOVA Table for % Mn of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.000530494	1	0.000530494	0.97	0.3527
Within groups	0.0043591	8	0.000544888		
Total (Corr.)	0.00488959	9			

APPENDIX 13: **NOVA Table for %Fe of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.00189723	1	0.00189723	0.52	0.4907
Within groups	0.0290958	8	0.00363698		
Total (Corr.)	0.030993	9			

APPENDIX 14: **ANOVA Table for %Cu of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1.26025E-10	1	1.26025E-10	0.00	0.9685
Within groups	6.05785E-7	8	7.57232E-8		
Total (Corr.)	6.05911E-7	9			

APPENDIX 15: **ANOVA Table of %Cd of SSC and HSC**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.00000678152	1	0.000006781 52	0.01	0.9313
Within groups	0.00686189	8	0.000857737		
Total (Corr.)	0.00686867	9			

APPENDIX 16: ANOVA Table for %NH4 of SSC and HSC

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.000060713	1	0.000060713	0.04	0.8496
Within groups	0.0126585	8	0.00158231		
Total (Corr.)	0.0127192	9			

APPENDIX 17: ANOVA Table for %NO3 of SSC and HSC

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0.00554508	1	0.00554508	9.14	0.0165
Within groups	0.00485442	8	0.000606802		
Total (Corr.)	0.0103995	9			

APPENDIX 18: **ANOVA Table for TO of 75 by Days**

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	191.286	6	31.881	18.86	0.0000
Within groups	23.6667	14	1.69048		
Total (Corr.)	214.952	20			

ANOVA Table for CU 75 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	329.841	6	54.9735	11.33	0.0001
Within groups	72.75	15	4.85		
Total (Corr.)	402.591	21			

ANOVA Table for SP 75 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	124.106	6	20.6843	18.62	0.0000
Within groups	16.6667	15	1.11111		
Total (Corr.)	140.773	21			

ANOVA Table for WM 75 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	64.5303	6	10.7551	2.72	0.0543
Within groups	59.3333	15	3.95556		
Total (Corr.)	123.864	21			

ANOVA Table for TO 100 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	15.8409	6	2.64015	5.87	0.0025
Within groups	6.75	15	0.45		
Total (Corr.)	22.5909	21			

ANOVA Table for CU 100 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	379.856	6	63.3093	25.38	0.0000
Within groups	37.4167	15	2.49444		
Total (Corr.)	417.273	21			

ANOVA Table for SP 100 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	59.8409	6	9.97348	6.04	0.0022
Within groups	24.75	15	1.65		
Total (Corr.)	84.5909	21			

ANOVA Table for WM 100 by Days

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	27.8561	6	4.64268	2.97	0.0406
Within groups	23.4167	15	1.56111		
Total (Corr.)	51.2727	21			