STANDARDISATION OF ORGANIC MATERIALS AS AMENDMENT FOR SOIL AND SOILLESS MEDIA IN URBAN HORTICULTURAL PRODUCTION SYSTEMS

BY

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DECLARATION

I hereby declare that, except for references to other people work which have been duly acknowledged, this is my own work towards the award of a Doctor of Philosophy (PhD) Degree and that no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

A survey was carried out in Tamale and Kumasi among horticultural practitioners from March 2012 to June 2012 and subsequently, experiments were carried out from June 2012 to June 2015 to select and standardise organic materials as media for urban horticulture. Following the survey, i) single species sawdust *(SS)*, ii) mixed species sawdust *(MS)* and ii) Rice husk (*RH*) were each co-composted with poultry manure in 2:1, 3:1 and 4:1 volumetric ratios of feedstock to poultry manure. This resulted in nine compost-types (formulations) being *2SS*, *3SS*, *4SS*, *2MS*, *3MS*, *4MS*, *2RH*, *3RH and 4RH*. Experiments were set-up in greenhouse and in the field to determine the rate of application of compost and biochar as amendment in soil and soilless media for vegetables and ornamentals. Treatments included compost-type: topsoil and compost-type: biochar mixes in soil experiments as well as compost-type: biochar mixes as soilless media. Competely Randomised Design was used for greenhouse experiments and Randomised Complete Block Design for the field experiment. The 2SS compost matured earliest (8 weeks) with Carbon: Nitrogen ratio (C: N) of 15 and highest nitrogen level of 2.46 %. The 1-part 2RH compost + 3 parts topsoil as well as 1 part of 2SS compost + 3 parts topsoil were the best for vegetables. The 2 parts of 2MS + 3 parts topsoil was the best for ornamentals. Sawdust compost (at 10 t/ha) + sawdust biochar (at 5 t/ha) was the best compost biochar mix for field production of vegetables. The 1 part of 2RH compost + 2 parts rice husk was the best media for greenhouse zinnia production. The 2SS compost + SS biochar was best media for greenhouse production of vegetables. The present study has clearly demonstrated that organic wastes which are currently causing environmental challenges to urban authorities can be developed into nutrient rich media suitable for horticultural production and urban greening.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Urban horticulture is a broad term referring to the growing and utilization of horticultural plants and their products in the urban environment. It involves both production horticulture where plants are produced for their edible products, and ornamental horticulture where plants are exploited for their functional and aesthetic uses in the urban environment (Mougeot, 2000; Robinson, 2009). Urban horticulture focuses on the functional use of horticulture which results in improving the surrounding urban areas by maintaining ecological integrity of the urban landscape (Robinson, 2009). Such ecological integrity leads to the creation of opportunities for urban greening, creation of microclimates, urban waste recycling, protection of urban landscape and biodiversity conservation (Van Veenhuizen, 2006). Consequently, urban horticulture creates opportunities for income generation, market development and employment.

In Ghana, urbanization, in the last three decades, has created big markets for horticultural products but this huge opportunity has been compromised by limited urban production spaces coupled with nutrient depletion of these spaces arising from the continuous cultivations to satisfy the huge markets. Urban farmers` response to the declining productivity has included use of inorganic fertilizers, reuse of wastewater and landfill (refuse dump) soil (Jim, 1998; Amarchey, 2005; Omotayo and Chukwuka 2009; Appeaning Addo, 2010; Abdul *et al*., 2011). However, the high cost of inorganic fertilizer coupled with their negative effects on soil properties have limited their use by farmers resulting in declining yields. This situation could be reversed with the identification of alternatives to the inorganic fertilizer for urban farming (Boateng *et al.*, 2007).

Animal manure and composts are highly favoured alternatives of farmers. Farmers have traditional knowledge of soil fertility enrichments using manures including compost types which is usually not well done. Poorly composted manures often lead to the release of excess nitrogen (N), which can be injuries to plants or may result in leaching of nitrate into water bodies. On the other hand, poorly composted organic residues may have very high C: N ratios with the consequence of N immobilization when applied to soils, resulting in poor crop performance.

A plausible strategy to for ensuring the production of quality compost to standardize the production using locally available organic materials, as well as identifying appropriate application regimes. Matured compost usually imparts good physical and chemical properties to growing media for crop poduction.

Standardisation organic amendments made up of compost and biochar is therefore imperative. Standardised organic amendments would be useful in the production of nutrient rich vegetables and aesthetic ornamentals. Improved horticultural production would enhance the use of organic waste materials such as sawdust and rice husk which attract high cost for disposal and at the same time are environmental menace.

Biochar produced from partial combustion or pyrolysis of organic material provides several desirable physical and chemical properties to soil. Biochar and compost mixes could be useful amendmment for media use for growing horticultural crops.

Improved horticultural production using a combination of compost and biochar would result in improved food security, nutrition, health, livelihoods and consequently national development.

The underlining hypotheses for this study therefore were:

1. There are no differences in knowledge and adoption of common soil amendments in urbn areas of Ghana
2. Co-composting of organic materials and addition of biochar can improve the quality of of organic matereials for soil fertility improvement
3. From compost-biochar mixes soilless media can be developed to replace the high cost imported media used in greenhouses in Ghana

These hypotheis were tested using a survey and a series of stand alone experiments.

1.2 OBJECTIVES OF THE STUDY

The general objective was to select and standardize potential organic materials for composting and formulating as organic amendments for application in urban horticulture.

Specifically the objectives were to:

1. Determine the types, availability and uses of organic amendments in urban areas of Ghana
2. Determine the quality, stability and maturity indices of compost formulated from selected feedstock in urban areas of Ghana
3. Determine the yield response of vegetables and ornamental plants to different rates of application of compost and compost-biochar mixes to soils and soilless media under greenhouse and field conditions

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 THE URBAN POPULATION AND URBAN HORTICULTURE

Schell and Ulijaszek, (1999), projects that 65 % of world population will reside in urban areas by 2025. UN-HABITAT, (2009), puts the urban population in Africa at 40 %, with urbanization rate of 4-10 % annually. According to Awitie *et al.* (2000), more than one third of the population in Africa already live in urban cities and by 2025, the rapid urbanisation in Africa could lead to increasing food insecurity, underemployment and high food prices in the cities. Urban areas already produce some 15 to 20 % of the world's food (Armar-Klemesu 2000; Dreschel and Gyiele, 1998)

2.1.1 Understanding Urban Horticulture (UH) and its Challenges

Urban horticulture (UH), is defined as the cultivation of crops for food and other uses within and around cities (Mougeot, 2000). Gündel (2002) defined UH as agricultural production, and processing and distribution activities within and around cities and towns. These activities according to Gündel (2002) utilize urban resources such as land, water, energy and labour that are in demand by other urban activities.

2.1.2 Urban Horticulture and the Urban Market in West African Cities

West Africa covers an area of about 7.3 million km^2 with an estimated human population of 263 million, of which 51 % depends on agriculture (FAO, 2003). The urban population alone amounts to 125 million and it is expected to reach 250 million by 2030 (Drechsel *et al.*, 2006, Figure 2.1).

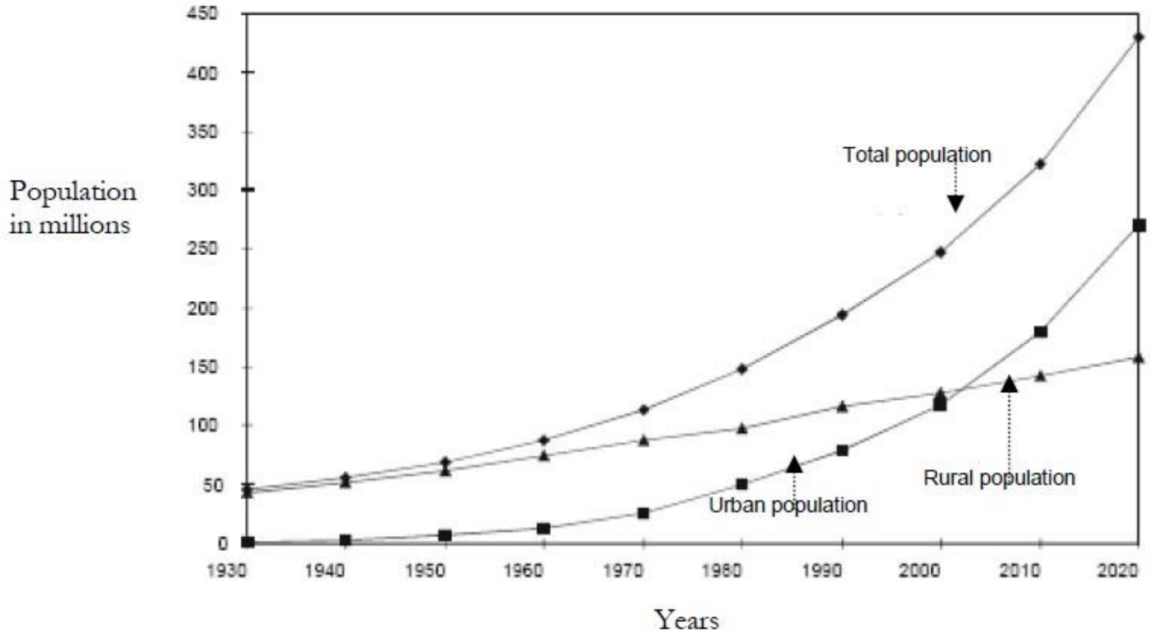

Figure 2.1 Population trend in West Africa (*Cofie et al., 2005)*

The most urbanized countries in West Africa include Ghana, Nigeria, Senegal, Cameroon, Burkina Faso and La Cote d'voire. Urban agriculture in cities of these countries are influenced by the nature of the urban populations including their food habits and lifestyles. The history of urban agriculture in West Africa is as old as the coming of European colonialist into Africa. The European merchants established horticultural gardens around their forts and castles. The expatriates also became important market for local farmers who had learned the new techniques of growing vegetables. European settler farms and Botanical gardens such as the Aburi botanical gardens became important horticultural supplies centers for the growing urban market in Accra. Events leading up to and during the first and second world wars also provided a niche market for vegetable production to meet the demand of American and British forces (Cofie 2005; Drechsel *et al*. 2006). About

160 ha and 300 ha of land in Accra is currently grown to local and exotic vegetables respectively (Oboubie *et al*., 2006).

In Ghana, plot sizes per farmer in the urban core vary between 0.01 and 0.02 ha and up to a maximum 2 ha in the peri-urban areas. In Accra about 47 hectares are under vegetables whiles and 251 hectares under mixed cereal-vegetable systems. About 100 ha are put under vegetable irrigation in the dry season. Over 50-70 additional hectares are distributed over 80,000 tiny backyards involving nearly 60% of Accra's houses (Oboubie *et al.,* 2006). In Kumasi, there are about 41 ha under vegetables cultivation in the city core and about 12,000 hectare under irrigated vegetable farming in the peri-urban areas. Over 60,000 households in Kumasi are involved in urban horticulture. In Tamale, The total area under cultivation is about 33-40 ha in urban core and more than 1000 ha in the peri-urban area. Smaller plot sizes results in practitioners putting the land under continuous cultivation all year round (Oboubie *et al*., 2006).

Cofie *et al*. 2003 estimates that in Douala, about 16% of the households are active in urban and peri-urban agricultural practices involving both crop and animal productions. According to Mbaye and Moustier (2000), urban production in Dakar meets 60% of the city's demand for produce and an estimated 70% of Senegal's total poultry demand. More than 3 percent of the total population in Abidjan, 44 % in Ouagadougou and 35 % in Yaoundé (Cameroon) are involved in urban agriculture. (Cities Farming for the Future 2006; Brinkmann *et al*., 2012).

Factors influencing the growth of urban agriculture in WA include

- Increasing urban population (Mougeot, 2000; Cofie *et al*., 2005)
- Increasing food demand and changing food habits (Mougeot, 2000)
- Increasing awareness of food safety issues (Drechsel *et al.*, 2000; 2001; 2002; Amoah *et al*., 2005; Oboubie *et al*., 2006)
- Increasing incomes (Van Veenhuizen, 2006; Shackleton *et al*., 2009)

2.2 CHARACTERISTICS AND BENEFITS OF URBAN HORTICULTURE IN GHANA

In Ghana, urban horticulture involves the growing, processing, and distribution of food in town and cities. It also includes the aesthetic development of the urban environment through intensive ornamental plant cultivation (Abubakari and Mahunu, 2007).

Urbanized towns in Ghana where urban horticulture is more advanced include Accra, Kumasi and Tamale, Takoradi, Sunyani, Cape coast, Bolgatanga and Wa. The major types of urban horticulture practiced in Ghana include vegetable crops production, fruit crops production and the production of ornamental plants. There are two main forms of urban crop farming in Ghana. These include; (i) open-space production for the urban market, and (ii) Subsistence backyard gardens where vegetables, medicinal plants and fruits are produced mostly for domestic uses (Oboubie *et al*., 2006). In both market gardens and backyard gardens vegetables are the dominant crops produced and these include green pepper, tomatoes, lettuce, cabbage, onions, spring onions and cauliflower (Kumah *et al.*, 2011). While majority of backyard gardens are under rain fed conditions, most market gardens are supplemented with irrigation. Pollution resulting from industrial activities and breakdown of urban sanitation infrastructure are known to lower the quality of irrigation water especially in the dry season. This has been shown to pose serious health risks to the producers and consumers of vegetables and necessitating sustain intervention in good irrigation practices and food safety issues (Drechsel *et al.*, 2000; 2002; Mensah *et al.*, 2001; Amoah *et al.*, 2005; Oboubie *et al*., 2006; Amoah *et al.*, 2007).

Development of lifestyle horticulture contributes to urban green infrastructures which include green belts, public gardens and play grounds. These green infrastructures are generally believed to provide important ecological services besides their role in human well-being (Cameron *et al.*, 2012). The development of standard soil amendments is central to building a resilient urban green infrastructure especially in changing climates.

One of the challenges confronting the integration of urban horticulture in urban land use plans is the uncontrolled expansion of residential and industrial settlements. The city of Kumasi for example expanded from 2.8 km in 1950 to 9.8 km radius in 2010 (Quagraine, 2011). This expansion is reported to have impacted heavily on the urban ecology and reduced the ability of the urban ecology to offer critical ecosystem services such as erosion control, air purification, heat island reduction and soil remediation (Mensah-Bonsu and Owusu-Ansah, 2011).

2.2.1 Urban Horticulture and Soil Amendments Use

The role of inorganic fertilizer in promoting productivity is well documented. However, the dangers of these inorganic fertilizers have also been widely reported (Agyarko &

Asante, 2005; Amoding *et al., 2005;* Omotayo *et al.,* 2009; Cofie *et al.,* 2010; Fening *et al.,* 2010 & Ogunwole *et al.,* 2010).

Manure, loam and composted crop residues are the most popular soil amendments and also the most widely used medium for ornamental plants in nurseries across Ghana. However, use of uncomposted manures often leads to the supply of too much N, which can be injuries to plants or may results in leaching of nitrate into water bodies. Poorly composted crops residues may have very high C: N ratios and may lead to nitrogen immobilization when applied to soils.

The development, standardisation and application of soil amendments in fragmented urban horticultural units is critical in sustaining and boosting plant growth and yield in the face of space limitation and climate change. Long term application of well decomposed compost or soil amendment would most likely increase crop yield and N use efficiency, enhance OM build up, reduce accumulation of NO_3-N salts and contaminants and thus contribute to environmental quality. Understanding C fluxes and N availability in the context of nutrient balances in compost production systems would lead to the identification of management options that would increase N availability, enhance microbial activity and improve CO_2 evolution and C storage in the soils (Liang, *et al.*, 2011). Applying compost to the soil reduces greenhouse-gas (CO_2, CH_4, N_2O) emissions that are associated with the widespread use of inorganic fertilizers (Barbanti *et al.*, 2010).

2.2.2 Urban Soils and Compost Standards

Urban growers are increasingly becoming aware of the quality of compost and are making specific demands for specific situations. The qualities of good compost include high stability and low salt content (Sæbøa and Ferrini, 2006).

Designs of composting systems should take into consideration quantities of materials, dry matter content, nitrogen losses and the volumes of compost produced in relation the area of application (Michel *et al*., 2003).

2.3 POTENTIAL SOIL AMENDMENT FOR URBAN PRODUCTION IN GHANA

In many developed countries, peat based growing media or other media with similar properties are widely used in commercial horticultural production systems. The recent hikes in prices of peat and the issues of climate change is now stimulating discussions and research into developing substitute for peat.

The need to recover nutrients from organic waste has been the dominant discourse in Ghana and composting of crop residues and municipal solid waste have dominated such discussions (Drechsel, and Gyiele 1998; Kindness, 1999; Cofie *et al.,* 2003; Drechsel *et al.,* 2004; Cofie *et al*., 2005; Danso *et al.,* 2006; Cofie *et al.,* 2008; Adamatey *et al.,* 2009). Nutrient recovery and the use of manure to improve soil physical properties have also been given adequate attention in the ensuing debate (Yangyuoru *et al.,* 2006; Agyarko, 2007). The recommendations contained in the works cited so far have relevant application in land management, nutrient recovery and closing the so called “nutrient loop” Quality, standards and technological issues however, limit the safe use of organic materials, especially for urban vegetable production and landscaping.

2.4 AVAILABILITY AND CHARACTERIZATION OF ORGANIC MATERIALS FOR SOIL AMENDMENT IN GHANA

Organic materials that have been studied for their potential development and application in soil fertility improvement include crop residues, agricultural by-products, forestry residues, wood processing waste and organic portion of Municipal Solid Waste (MSW). According to Duku *et al.,* (2011), about 4159 x 10^3 tons of crop residues are generated annually in Ghana. However the small scale production units and the widely disperse nature of farms in Ghana make collection of crop residues for composting difficult and expensive. Assuming 30 % recovery of materials during composting, crops residues alone have the potential to generate 1,386 x 10^3 tons of compost annually. Among crop residues, maize stalks are the most abundant (1402 x10^3 tons), followed by sorghum (779 x10^3 tons), cocoa pod husk (595 x10^3 tons), millet (408 x10^3 tons), rice straw ((308 x10^3 tons), and coconut coir (170 x10^3 tons) (Duku *et al.,* 2011). Anon (1998) noted that food processing waste such as palm kernel and palm oil sludge, palm fibre, palm kernel shell, cassava peels, cocoa pod shells, coconut shells, sheanut shells were ideal feedstock for composting. However, these food processing have competing uses in local industry and as feed for livestock.

Holmes (2004) identified composted bark, green compost and loam, coir, perlite, fine bark and wood fiber as substitute for peat in commercial horticulture in England. Coir is also reported to have qualities relevant to its use as a growth medium (Evans *et.al*., 1996; Prasad, 1997).

Duku *et al*. (2011) also cited elephant grass (*Pennisetum purpureum*), guinea grass (*Panicum maximum*) and *miscanthus* (*Mischanhus gigantues*). Forestry residues generated annually is (360 x 10^3 tons) and wood processing waste is (128.250 x 10^3 tons). Municipal Solid Waste (MSW) includes household waste, market waste and industrial waste from cities and urban centers. Duku *et al*., (2011) reports that about 150-200 kg per person of MSW is generated annually in Ghana with the ten regional capitals alone accounting for 2 million tons per year. Presence of large portion of inert materials and heavy metals in MSW creates difficulties in composting and application of MSW compost.

Leconte *et al.*, 2009, characterized feedstock for composting and found that poultry manure had greater N concentration (N= 3.7 %) and lower organic carbon (29 %) compared to sawdust (N=0.6, and C=53.2 %) and rice husk (N=0.4 % and C=42.0 %). Poultry manure was also found to have higher pH (8.0) and Ca (19.4 %) concentration than sawdust (pH=6.7 and Ca=1.6 %) and rice husk (pH=6.4 and Ca=3.8 g/kg). Sawdust was however found to have higher total organic carbon (TOC) and more lignified than rice husk. In characterising feedstock for composting, the C: N ratio is critical as they determine the length of the thermophilic phases and also the maturity of and stability periods of the final compost. The optimum C: N ratio for matured and stabilised compost is 12:1 to 15:1. C: N ratios less than 10:1 indicate situations of incomplete composting associated with higher levels of N manures. C: N values more than 25:1 indicate presence of raw carbonaceous materials which when applies to soil results in severe N drawdown (Saeboa and Ferrini 2006). The N level of manures varies depending on the type of livestock and also the system of production. Poultry manure is reported to have the highest N levels among domestic livestock (Ahmed *et al*., 2007; Gao *et al*., 2010; Munawar and Riwandi, 2010; Yun Zhang and yang He, 2006). The N level of poultry manure in the cage system is reported to be between 3.63 – 5.30 %. In the broiler house, the N content of manure is 2.40-3.60, while in the deep litter system values ranging from 1.70-2.20 are commonly reported (Amanullah *et al.*, 2010). The value of N content is the most common indicator of the fertilizer value of organic amendments.

2.5 COMPOSTING TECHNOLOGIES

Besides creating good soil amendment, composting is one good method of reducing the quantity of wastes that are sent to landfills, burnt or left in a manner that cause pollution of land and water bodies.

There are different methods of preparing compost. These include:

- The Indoor method: open air composting where materials pile in layers forming a hip
- The Bangalore method: closed structure using bricks to build the structure and materials piled in layers
- Pit composting: A pit is dug in the ground with specific dimensions and materials piled in layers
- Trench composting: compost materials are piled in trenches and crops grown along the trenches
- Basket composting: waste materials are kept in basket and allowed to decomposed
- Windrow: large scale composting where materials are pile in windrows

- Wooden bin: compost materials are piled in a wooden bin (about 1m cube) and allowed to decompose (HDRA- the organic organization, 2008).

Another method of composting is vermicomposting. Vermicomposting is composting done with worm. The worms best suited for vermicomposting are red manure worms (*Lumbricus rebellus*) and red wigglers (*Eisenia foetida*). The night crawler (*Lumbricus terrestris*), needs cool soil temperatures and do not survive in a worm box. Vermicompost has been used for the production of vegetables and bedding plants (Atiyeh *et al*., 2001; Bachman and Metzger, 2008)

2.6 THE COMPOSTING PROCESS

2.6.1 Moisture and Temperature Changes during Composting

Adequate moisture regime for the compost pile is between 35 and 65 %. Too much moisture will lead to the setting in of anaerobic conditions. Initial moisture values should be between 50 and 65 % and final values between 35 and 40 % (A and L Canada laboratories, 2014). Moisture is the dominant factor influencing aeration and temperature (Boulter *et al*., 2000).

The composting process is characterized by high temperatures, large organic matter breakdown, increasing microbial population and activity and reducing supply of O_2. During the first 4-5 days, the compost pile is characterized by fermentation which results in enhanced breakdown of highly lignified carbonaceous materials. This stage is associated with significant multiplication of microorganisms. Maximum fermentation takes place at a temperature of 60-70 ^{O}C. Availability of oxygen and the right moisture regime (35-65 %) are critical in maintaining microbial population. The nature of carbonaceous materials ultimately determines the length of the thermophilic phase (Gao *et al.*, 2010). Higher values of respiration (340-466 mg/kg/h) were reported at early stages of composting decreasing to 37-90 by maturity period of compost. (Leconte *et al.*, 2009). Leconte *et al.* (2009) found no correlation between microbial respiration and compost temperature and attributed this finding to thermic inertia which was thought to be the result of exothermic hydrolysis reaction. This is in contrast to the finding of Tiquia *et al*. (2002), who reported that the compost temperature was related to microbial activity. Reduced pH and very high level of nitrification was also found to coincide with the end of thermophilic phase. Further oxidation of ammonia to nitrate mediated by nitrifying bacteria was also found to be very active at mesophilic temperatures. Higher temperatures were also found to be associated with ammonia volatilization. The thermophilic temperatures of 60-70 ^{O}C are also critical in killing weed seeds and pathogens that may be in the feedstock. Temperature is also strongly influenced by the depth of composting. The middle part of compost is known to be warmer than the upper and lower depths (Leconte *et al.,* 2009). NH_4 levels drops with increasing temperature. Turning of compost which is a recommended practice during composting have been shown to reduce temperature to mesophilic levels within 21 days. Unturned piles remained at thermophilic levels until after 42 days (Tiquia *et al*., 2002). Lignin and carbon decomposition are highest at thermophilic temperatures (Brewer and Sullivan, 2001). NH_4 nitrifying bacteria are active at these stages, feedstock with higher C: N generates higher temperatures needed to kill pathogens and weed seeds (Gao *et al*., 2010). Changes in temperatures are generally known to correlates well with microbial respiration and different parts of the compost pile have different temperature regimes. Nitrogen and P decomposition occur at mesophilic stages whilst carbon decomposition is highest during the thermophilic stages (Zhang and He, 2006). Temperature increases occur during the early stages of composting as sugars and proteins get degraded (Boulter *et al.*, 2000). Temperature appears to be the dominant factor influencing microbial activity. Metabolic heat may increase the pile temperature to 70 ^{O}C. This temperature is needed for pathogen reduction but it can also kill beneficial microbes. CH_4 production increase with increasing temperature and low redox conditions created by methagenic bacteria (Boulter *et al*., 2000). Higher temperatures inhibit nitrifying bacteria resulting in less production of $NO_{3.}$

2.6.2 Nitrogen and Carbon Dynamics during Composting and Compost Quality

Nitrogen provides the energy for the breakdown of carbon during composting. Carbon becomes the building blocks of 50% of microbial biomass. The following are C: N ratio for various feedstock:

1. Higher carbon feedstock	**C: N**
Plant leaves	30-80:1
Straw	40-100:1
Wood and sawdust	100-500:1
Bark	100-130:1

2. Higher N feedstock **C: N** Vegetable

waste	15-20:1
Grass clippings	15-25:1
Manure	5-25:1

According to Brewer and Sullivan (2001), feedstock with higher fraction of decomposable C promotes higher rates of microbial respiration. Water soluble hydrolysable C is accessible to microbes this makes up the 1/3 of the material that is loss during composting, suggesting that reduction in water soluble C is an indicator of compost maturity (Brewer and Sullivan, 2001, Gao *et al*., 2010, Boulter *et al*., 2000). The carbon form becomes increasingly recalcitrant with increasing time of composting (Brewer and Sullivan, 2001). Low degradation of C during composting may be as a result of lignified feedstock with higher levels of tannins (Bakry *et al*., 2012). Compost may supply or immobilize N in plant root system. During composting, NH_4 is oxidized to NO_3 by nitrifying bacteria Nitrogen does not accumulate at the early stages of composting but is consumed in building microbial biomass. In feedstock with lower C: N, Higher NH_4 production and Higher pH leads to the release of NH_3 gas. In high C: N feedstock, less N is loss. At the end of composting, NO_3-N levels should be higher than NH_4-N (Xiying Hao, 2007). The limit for the ratio of NH_4 to NO_3-N is given as 0.16 (Gao *et al*., 2010). Whilst N decomposition occurs at mesophilic temperatures, C degradation occurs at thermophilic temperatures (Zhang and He, 2006, Sommer, 2001, and Ogunwande *et al., 2008*).

Leconte *et al.,* (2011) reported that the quality of sawdust and rice husk based cocompost with poultry manure was higher in terms of N and P. the level of the Nutrient in the final compost was found not to be dependent on poultry manure but also the nature of bulking materials. Organic matter breakdown leads to losses of total organic carbon (TOC). The activity of Ammonia Oxidising Bacterial (AOB) is suppressed under high pH and high NH_4 conditions. The NH_4 and $N0_3$ fluxes influence the level of EC and pH (Kato *et al.,* 2005). Compost maturity and stability have been the two most common criteria for assessing the quality and safety of compost for application in crop production. According to the California Composting Quality Council, (CCQC, 2001) Stability refers to a specific stage or decomposition or state of organic matter during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material. Thus stability refers to the relative impact of the compost product on nutrient availability and the consistency of physical properties of the soil. The CCQC define Maturity as the degree or level of completeness of composting. Immature compost may cause N starvation, delayed plant growth and phytotoxicity. They may also contain harmful microbes, weed seeds and have unpleasant odours (Kato *et al.,* 2005). In matured compost there are higher levels of NO_3 and lower levels of NH_4. Kato *et al.* (2003) used temperature, NH_4, NO_3 and microbial respiration as determinants of compost maturity.

Turning of compost have been shown to cause C losses but does not affect losses of N (Tiquia *et al.,* 2002).

2.6.3 Changes in pH and EC during Composting

Commercially produced compost has pH between 6.7 and 7.7. pH in potting media increases with the addition of compost. This shows that compost has a buffering effect on growth media. pH is known to affect nutrient availability in potting media (Wilson *et al*., 2001). At higher pH, micro nutrients and P become less available and at lower pH major nutrients are reported to become less available and this may trigger the toxicity of micronutrients. Decreasing pH may result from anaerobic conditions in compost. Anaerobic conditions lead to the accumulation of organic acids (A and L Canada laboratories, 2014). Organic acids include acetic acid and propionic acid. pH therefore partly determines the toxicity of potting media to seeds and seedling development (McClintock and Diop, 2005). pH has also been reported as good indicator of the progress of composting (Brewer and Sullivan, 2001). pH of compost depends partly on the nature of the initial feedstock. Lignin decomposition is reported to occur at higher temperature. Feedstock of higher C: N is known to generate higher pH and ammonia gas during composting. N_2O emissions are also known to be highest at low pH. pH stabilizes as a result of ammonia volatilization and H^+ release from microbial nitrification (Gao *et al*., 2010). pH levels less than 5 or more than 8 inhibits N mineralization (Amlinger *et al*., 2003). N release in sawdust was found to correlate positively with total nitrogen and negatively with pH (Leconte *et al*., 2011).

EC indicates the soluble salts content of the compost and affects seed germination and root development. Higher EC is noted to cause severe phytotoxicity (Wilson *et al*., 2001). Good salts result from the presence of k, Mg, Ca, NO_3 and NH_4. Toxic salts results from the presence of Na and Cl_2. If the EC is less than 0.75, the media will require nutrient supplementation. Acceptable range of EC is between 0.75 and 2.35. Tender plants are sensitive to EC of 3.5-5 and compost of this EC content need to be diluted for tender plants. Compost with EC of 5 or more needs to be applied in lower concentrations or used as mulch for established plants (Brewer and Sullivan, 2001). Increase in EC could be due to release of mineral salts that occur during the active phase of composting (Gomez-Brandon *et al*., 2008, Gao *et al*., 2010).

2.6.4 Greenhouse Gas Emissions (GGE) during Composting

The main greenhouse gases produced during composting include CO_2, N_2O and CH_4. Microbial transformation of CH_4 and N_2O in compost is reported to be similar to the same process that takes place in soils and in wastewater. Landfilling accounts for over 12 % of the total global CH_4 emissions (Adhikari *et al.*, 2013). Organic waste composted with high N materials was shown to reduce GGE, especially N_2O by 40-60 %. The presence of large amounts of organic compounds and minerals stimulates the consumption of O_2 which is essential for gases exchange and transformation. When the compost process is well managed, little methane is produced. N_2O can be generated as a by-product of nitrification and denitrification (Kebreab *et al.*, 2006; Xiying Hao, 2007; Leconte *et al.*, 2009). CH_4 and N_2O emissions depend on the degradation rate which is affected by the bulking agents and the nature of the initial compost materials. Adhikari *et al.*, (2013) reported that composting of organic waste can lower GGE between 0.03-8.0kg CH_4 (ton of waste treated) equivalent to 200 kg of CO_2. Nitrogen and C transformation may increase temperature from 60-70 ^{O}C and causing emission loses of ammonia and CO_2 (Sommer and Dahl, 1999). Michel *et al.*, 2003 found that in sawdust amended compost significant negative correlations existed between C: N and N losses R^2=0.78 and C losses (R^2=0.86). Covering compost piles was shown to reduce N emissions by 12-18 %. Most of N losses are due to volatilization, 20 % to leaching and only a little to denitrification. Covering up the pile and compacting the materials were also shown to reduce K losses which are reported to be 8-16 % in uncovered piles (Sommer, 2001).

During storage of deep litter manure, gaseous N losses can be as high as 20-40%. Emissions of CH_4 and N_2O from manure contribute 5-6 % of global emissions of CH_4 and 7% to the global emission of N_2O (Sommer, 2001).

2.7 EFFECTS OF COMPOST ON PLANT GROWTH AND DEVELOPMENT

Maximum nutrient availability in soils occurs at slightly acidic to neutral pH. Addition of compost increases the pH of acidic soils and therefore making nutrient more available for plant growth. Compost addition in soil or growth media may also correct imbalances in salt content. Addition of compost is reported to have triple the N content of sandy soils (Schulz *et al*., 2014) Compost increases both N and TOC in soils, but the effect of this is more pronounced in sandy soils than in loamy soils. Moreover, P, K, Ca, Mg and Na levels are reported to be elevated in soils with increasing addition of compost, while the levels of Al and Na decreases (Schulz *et al*., 2014). Presence of salts can lead to chlorosis and root injury which may cause root diseases and interfere with nutrient uptake. Excess salts are also implicated in poor germination and seedling development (A and L Canada laboratories, 2014).

Summary of importance of Compost

- Release nutrients slowly and promote healthy root development (Barbanti *et al.*, 2010),
- Improves soil tilth and increases water holding capacity of substrates (Agegnehu *et al.*, 2015; Aggelides, 2000)
- Increases microbial diversity and provide buffering effect on soils (Kowaljow and Mazzarino, 2007; Xu *et al*., 2012).

The N effect in the first year of compost application is reported to be 5-15 % and 2-8 % per annum subsequently. Application of 15 tons of compost increased the soil humus load by 0.4-0.5 in 20 years, while the application of inorganic fertilizers decreased the humus load by 0.5 % in the same period (Amlinger *et al*., 2003,). This implies compost adds on humus while inorganic fertilizers reduces humus content. Compost has wide application in Agriculture, Forestry and Horticulture for crop production, land remediation and restoration (Zhang *et al*., 2012).

2.8. BIOCHAR IN SOIL AMENDMENT

Biochar is carbonized material produced by partially combustion or pyrolysis of dry biomass. Rice husk biochar has been studied for its potential to remedy problematic soils. Rice husk biochar contains high proportion of plant nutrients (Carbon, Silicon, Phosphorus, Potassium, Calcium, Magnesium, Iron and Zinc) with a pH of 8.6 that can be used for amending problematic soils (Haefele *et. al*., 2011). According to Warnock *et al*. (2007), biochar also enhances the physical properties of soil. Biochar enhances the porosity and water holding capacity, as well as the inoculation efficiency of root nodules bacteria and mycorrhizea. Application of biochar has also been shown to improve rooting medium for woody seedlings (Annapurrna *et.al*, 2005; Basu *et al.*, 2007; Agele *et al.*, 2010). As biochar is highly resistant to oxidative degradation, it has a higher potential of enhancing carbon sequestration in the soil (Lehmann *et al.*, 2006; Ogawa *et al.*, 2006).

A number of studies have focused on the use of biochar as sorbent for environmental contaminants such as heavy metals. Heavy metals are inorganic soil contaminants which when present in excess levels in the soil can cause toxic response to biota, humans and agro ecosystems. One of the techniques used to hinder the spread of contaminants in the soil is contaminant stabilization. The application of amendments that can bind pollutants in the soil have therefore become a very popular stabilization technique (Beesley *et al.*, 2010). Contaminant binding amendments are known to decrease leaching of trace elements, reducing their bioavailability, through various sorption processes. These include adsorption, formation of complexes, surface precipitation and ion exchange. Insitu application of amendments can therefore be used to reclaim, re-vegetate and restore contaminated agriculture and industrial area landscapes. Cr, Cu, Zn, As, Pb and Cd are the most common inorganic contaminants found in wastewater and industrial mining devastated landscapes. Various soil amendments have been studied for their potential to stabilize inorganic contaminants in the soil. Compost and biosolids have been extensively studied for their potential in stabilizing metals in the soil. A number of studies have focused on biochar potential for immobilizing metals in the soil (Beesley *et al*., 2010). Moreover, use of biochar has been shown to increase mobility of As. Biochar may also immobilize essential nutrient alongside metals when used as sole amendment in remediation programmes. The combination of biochar and compost may be effectively used to cure this limitation in biochar amendments and also increase our understanding of the interaction between amendment and contaminant retention over time (Beesley *et al*., 2010).

2.8.1 Biochar Use in Urban Horticulture

The main challenges confronting urban horticulture in the developing world are how to improve fertility and productivity while minimising the negative environmental consequences of production systems (Dempster *et al*., 2012). Decreasing use of mineral fertilizer and the use of biochar can improve soil fertility, sequester carbon and reduce the negative environmental consequences (Glaser *et al*., 2002; Lehmann *et al.*, 2006; Ogawa *et al*., 2006). Although biochar is known to decrease leaching of NH_4, it may stimulate leaching of NO_3.

The use of biochar is reported to enhance carbon sequestration and thereby reducing Greenhouse gas emissions (Lehmnan *et al*., 2006, Glaser *et al*., 2009; Yuan *et al*., 2012). Biochar also improves soil fertility and promotes plant growth (Marris, 2006; Sanchez *et al*., 2009; Steinbeiss *et al.*, 2009 and Gaskin *et al*., 2010). Biochar is also noted for its liming effects and thus increases soil pH, increases CEC and soil adsorption capacity (Chan *et al.*, 2008; Steiner *et al*., 2008; Novak *et al*., 2009; and Sohi *et al*., 2010). The reaction mechanism following application of biochar have been extensively explored (Deenik *et al*., 2011; Yuan *et al*., 2011; Hass *et al*., 2012 and Xu *et al*., 2012).

Where land is limited productivity per unit area can be increased with the use of organic amendments (Foley *et al*., 2011; Tilman *et al*., 2011). Biochar improves soil nutrient supply, enhances plant growth and yield an reduces GGE through carbon storage (Lehmann and Randon 2006; Major *et al*., 2010; van Zwieten *et al*., 2010; Ippolito *et al*., 2012; Zhang *et al*., 2012). Biochar improves water retention and plant available water (Downie 2011; Tammeorg *et al*., 2014). Biochar improves the soil as habitat for beneficial microbes (Thies and Rillig 2009). Effectiveness of biochar depends on the type of soil and the application rate of biochar. Combine use of compost and biochar is more beneficial (Fischer and Glaser 2012; Schulz and Glaser 2012). Combine use of compost and biochar improves nutrient and water retention (Liu *et al*., 2012). Use of organic amendments decreased volume of leachate and cumulative leaching volume was found to be inversely related with the above and below ground biomass. Yield of maize was increased by 98-150 % because of biochar and water use efficiency increased by 91-138

% as a result of manure biochar addition (Uzoma *et al*., 2011). Wheat biomass increased by 250 % and wheat grain yield by 18 % (Van Zwieten *et al*., 2010; Solaiman *et al*., 2010). Nutrient optimization is believed to be the reason for enhanced biochar effect on yield (Gaskin *et al*., 2010; Glaser *et al*., 2002; Lehmann *et al*., 2006). There are evidence of increase in microbial biomass as a results of biochar (Biederman and Harpole, 2013; Thies and Rillig 2009). Effect of biochar on wheat yield was sustained for two consecutive seasons without further addition of biochar (Vaccari *et al*., 2011).

2.8.2 The Potential of Biochar Feedstock as Soilless Medium

Soilless culture is commonly referred to all techniques for growing plants in solid media other than soil. Soilless media is seen as a good substitute for soil based production system. The problems associated with soil based production systems such as limited space, declining productivity, soil contamination with weed seeds, pathogens and heavy metals have increased interest in the development of soilless substrate (Sezen *et al*., 2006). The choice of feedstock for soilless media depends on the following factors:

- The physical and chemical properties of the feedstock such as, nutrient content and water holding capacity (Wilson, 1983; Alagha and Sangodoyin 2013; Steiner and Harttung, 2014; Lowry 2015)
- The effect of the substrate on plant growth and development (Verdonck *et al*., 1983)
- The yield and quality of produced obtained in using the media (Varis and Altay, 1992; Alan *et al*., 1994)
- The cost, local availability and users experience with the feedstock (Klougart, 1983; Verdonck *et al*., 1983)
- Re-usability of substrate for at least 2-3 years (Acuna *et al.*, 2005; Fernandes *et al*., 2006; Giuffrida *et al*., 2007; Rea *et al.*, 2008; Urrestarazu *et al.*, 2008)

Biochar has properties that make it ideal as a soilless substrate. Biochar is known to help in nutrient retention in growing media and this property could be very useful in regulating nutrient fluctuation especially nitrate fluctuation in soilless culture. Biochar is reported to have several horticultural applications including replacement of peat in soilless cultures (Vaughn *et al.*, 2013). According to Vaughn *et al*. (2013), replacing peat with biochar in potting media increase pH, bulk density, EC increased and marigold yield, but had variable effect on air field porosity. The physical quality and nutrient content of soilless substrates were reported to have improved with the addition of biochar into the media. Furthermore plant height as well as fresh and dry biomass weight of *Calathea insignis* was reported to have increased with the addition of biochar in growing media (Zhang *et al.*, 2012). Bedussi *et al.*, (2015) however, found higher levels of nitrate and ammonia in pore water of soilless culture to be related to biochar addition. This means that pore water may need to be contained in the media or recycled. Although, there is not much studies on the use of biochar in soilless culture, there limited information suggest the development of biochar as an alternative substrate for soilless culture will not only improve substrate and produce quality but also reduce cost of greenhouse substrate. Furthermore use of biochar in soilless culture could reduce substrate disposal problems (as it can be re-used) and mitigate climate change through carbon sequestration and reduction of greenhouse gas emissions (Steiner and Harttung, 2014; Gil *et al.*, 2015).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 SURVEY STUDY

A preliminary survey study was conducted in Tamale and Kumasi in the Northern and Ashanti Regions respectively from March 2012 to June 2012, to identify vegetable farmers and nursery operators who were using soil amendments and subsequently to identif current types, availability and uses of soil amendments in their activities. Questionnaire was used as survey tool to collect information on the amendment used by urban farmers.

Sixty semi-structured questionnaires were designed (Appendix 1) and administered to 30 farmers each from Tamale and Kumasi. The questionnaire captured the profile of farmers, the types of amendments and the level of usage of soil amendments. The farmer's knowledge of the use of soil amendments as well as the challenges facing farmers in using soil amendments was documented. In both Tamale and Kumasi, vegetable production areas where soil amendments were intensively used were selected. Tamale and Kumasi were selected through cluster sampling. Purposive sampling was used to select horticultural practitioners. In Tamale, urban farmers within the city center were selected and 30 farmers interviewed using the snowball sampling method (one farmer leads the researcher to another farmer). In Kumasi, 30 farmers cultivating vegetables around Kwame Nkrumah University of Science and Technology (KNUST) were also interviewed using the same sampling method. Tamale was chosen to represent the savannah area because it has the highest population in the region (371, 351) and is the most urbanised town in the savannah areas of Ghana. Kumasi represented the forest area of Ghana because it has the highest population (2,035,064) and is the most urbanised city in the forest area of Ghana (Ghana Statistical Services, 2010).

3.2 CHARACTERISATION AND FORMULATION, ANALYSIS OF FEEDSTOCK, COMPOST AND SOIL

3.2.1 Characterisation and Analysis of Feedstock

The physio-chemical composition of the feedstock was analysed in the laboratory. Fresh poultry manure was obtained from a layer facility the Faculty of Agriculture, University for Development Studies, Nyankpala campus. Fresh sawdusts were obtained from the Central Timber Mills in the Tamale. Rice husk was obtained from Savannah Agriculture Reseach Institute Rice Mills, near the Nyankpala campus. These organic materials were kept in a well ventilated room for one week before analysis. Fresh composite samples of poultry manure, sawdust and rice husk feedstock were air dried and analysed for moisture, bulk density, electrical conductivity (EC), total organic carbon (TOC), total nitrogen (TN), carbon nitrogen ratio (C/N), Cellulose, Lignin, Ext. P, Ca, Mg, K, Na.

Values for these parameters were averages of three samples.

3.2.1.1 Determination of moisture content of feedstock

Moisture content of feedstock was determined by oven drying samples at 105 ˚C for 24 hrs. The percentage difference between the wet weight and dry weight was calculated to represent the moisture content (Gardner, 1986).

3.2.1.2 Determination of Bulk density

A 50-ml measuring cylinder was weighed and 20 g of each replicate feedstock or compost sample put inside the cylinder. The measuring cylinder was tapped 10 times and the volume of sample (cm^3) in the cylinder recorded (Blake, 1965). The weight difference between the cylinder and sample was recorded and the density calculated as: Density of sample = mass g/Volume cm^3.

3.2.1.3. Determination of Electrical Conductivity (EC)

A 5 g of each of the replicate compost samples was oven-dried weighed into a 100 ml beaker and 25 ml distilled water was added to each beaker. The suspension was agitated intermittently by hand for 20 minutes. The beakers containing the suspension were allowed to stand for 30 minutes before EC measurements. The EC meter was calibrated with 0.01 N KCl solution. This gave a reading of 1413mS/m at 25^oC. The EC was determined by inserting the Electrode of the EC meter into the suspension (Rowell, 1994). Crison Basic EC meter CM39P was used for the determination of EC of all the compost samples.

3.2.1.4. Determination of pH

A 5 g of each of the replicate compost samples was oven- dried weighed into a 100 ml beaker and 50 ml distilled water was added to each beaker. The suspension was agitated intermittently by hand for 20 minutes. The beaker containing the suspension was allowed to stand for 30 minutes before pH measurements. The pH meter was calibrated with blank at pH of 7 and 4 respectively. The pH was determined by inserting the Electrode of the pH meter into the suspension (Nelson and Sommers**,** 1982) Crison Basic pH meter, PH29P was used for the determination of pH of all the compost samples.

3.2.1.5. Determination of Organic Carbon

Organic C was determined by the modified Walkley-Black Wet oxidation method as outlined by Nelson and Sommers (1982). Hundred milligrams (0.10 g) of plant material was weighed into 500 ml conical flask and 10 ml of 0.166 M (1.0 N) $K_2Cr_2O_7$ solution added, followed by 20 ml conc. H_2SO_4 and allowed to cool on an asbestos material for 30 minutes. 200 ml of distilled water was added followed by 10 ml of H_3PO_4 and then 1.0 ml of diphenylamine indicator solution. This mixture was then titrated with 1.0 M ferrous sulphate solution until colour changed from a blue-black coloration to a permanent greenish colour. A blank determination was carried out in a similar fashion in every batch of samples analysed without soil. Percentage carbon (C) was Calculated following the methods of Nelson and Sommers (1982).

3.2.1.6 Determination of Total Nitrogen

Total N was determined using the Kjeldahl digestion method (Okelabo *et al*., 1993). Two (2.0) grams of compost material oven dried and ground to pass through a 0.5 mm sieve was weighed into a 500 ml Kjeldahl digestion flask and one spatula of catalyst (copper sulphate + sodium sulphate + selenium powder mixture) followed by 20 ml of concentrated H_2SO_4 was added. The mixture was heated strongly to digest the plant material to a permanent clear green colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 10 ml aliquot of the digest was transferred into a Tecator distillation flask and 20 ml of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 N HCl solution. A blank digestion, distillation and titration were carried out as a check against traces of nitrogen in the reagents and water used.

Percentage nitrogen was calculated as given by Okelabo *et al*., (1993).

3.2.1.7 Dry Ash Digestion and Analysis for Phosphorus, Calcium, Magnesium, Potassium and Sodium

The procedure of Watanabe and Olsen (1965) was used for the analysis of P, Ca, Mg, K and Na. Prior to the determination, one (1.0) gram of feedstock sample was ashed at 500^{o}C over a period of 2 hours.

For phosphorus, a 5 ml aliquot supernatant digest of each compost replicate was pipetted into a 50 ml volumetric flask. Five (5.0) millilitres of ammonium molybdate – ammonium vanadate solution was added. Volume of mixture was made up with distilled water to the 50 ml mark and allowed to stand undisturbed for 30 minutes for colour development. Standard curve was developed concurrently with P concentrations ranging from 0.0, 5.0, 10.0, 15.0, 20.0 mg P / kg. The absorbance of blank, control and the samples were read on the Jenway Colorimeter at a wavelength of 430 nm (Watanabe and Olsen 1965). A graph of absorbance versus concentration (ppm) P was plotted. The blank and unknown standards were read and the ppm P was obtained by interpolation on the graph plotted from which P concentrations were determined for the formulae given by Watanabe and Olsen (1965).

Calculation:

P content (µg) in 1.0 g of plant sample = C x df

$$\text{P content (g) in 100 g plant sample, (\% P)} = \frac{C \times df \times 100}{1000\,000} = \frac{C \times 1000 \times 100}{1000\,000} = \frac{C}{10}$$

Where C = concentration of P (µg / ml) as read from the standard curve df

= dilution factor, which is 100 x10 = 1000, calculated as:

- 1.0 g of sample made up to 100 ml (100 times) ➢ 5.0 ml of sample solution made up to 50 ml (10 times)
- 1000 000 = factor for converting µg to g.

For K and Na, 1.908 g and 2.542 g of analytical grade KCl and NaCl respectively previously dried in an oven for 4 hours at 105°C were each dissolved in 200 ml of deionised water. The two solutions were mixed together and volume made up to 1000 ml. This gave a combined standard of 1000 ppm. For K, a calibration curve (standard curve) of 200, 400, 600 and 800 ppm was prepared. Similarly, a standard curve of 20, 40, 60 and 80 ppm was prepared for sodium. All the absorbance reading was taken using the flame photometer. The sample solution from the $HClO_4$ and HNO_3 was read on the flame photometer. From the standard curve, the concentration of K and Na were calculated using the particular absorbance observed for the sample (Mehlich, 1984).

Calcium and magnesium determination by EDTA titration involves addition of several reagents (Mehlich, 1984). For calcium, 5.0 ml of each of the compost replicate sample solution from the supernatant digest was transferred into a 100 ml Erlenmeyer flask. 10

ml of 10 % KOH solution was added followed by 1 ml of 30 % TEA. Three drops of 10 % KCN and few drops of EBT indicator solution. The mixture was shaken to ensure homogeneity. The mixture was titrated with 0.02 N EDTA solution from a red to blue end point (Mehlich, 1984).

For magnesium, 5.0 ml each of the replicate compost sample solution from the supernatant digest was emptied into a 100 ml Erlenmeyer flask. 5 ml of ammonium chloride – ammonium hydroxide buffer solution was added followed by 1 ml 30% TEA. Three drops of 10 % KCN and a few drops of EBT indicator solution. The mixture was shaken to ensure homogeneity. The mixture was titrated with 0.02 N EDTA solutions from a red to blue endpoint (Mehlich, 1984).

Magnesium in mg = Titre value of EDTA x 0.24

$$\% \text{ Mg} = \frac{mg\ Magnesium}{Sample\ wt} x\ 100$$

3.2.1.8 Determination of Lignin

Acid Detergent Fibre (ADF) was prepared following the method of Van Soest, (1963) A gram of the ADF was transferred into a 100 ml beaker and the content covered with 72% H_2SO_4 and cooled (5^{o}C). A 1.0 g asbestos was added and allowed to stand for 3 hours with intermittent stirring with a glass rod. The acid was diluted with distilled water and filtered with pre-weighed Whatman No. 1 filter paper. Glass rod and the residue were washed several times to get rid of the acid. The filter was dried at 100^{o}C and weighed after cooling in a desiccator. The filter paper was transferred to a pre-weighed silica crucible. The filter paper with the content was ashed in a muffle furnace at 500 ^{o}C for about 3 hours. The crucible was cooled and weighed in desiccator.

The ash content was calculated (Van Soest, 1963).

3.2.1.9 Determination of Cellulose

1g of each replicate compost sample was placed in large centrifuge tube. 25 ml of 1.25 % NaOH was added and the tube placed in boiling water for 20 min. Samples were centrifuge for 10 minutes at 3000 rpm and the supernatant pour off. 12 ml acetic acid and 2.5 ml HNO_3 were added and placed in boiling water bath for 20 min. Samples were poured into Gooch crucible and wash with hot water, alcohol, cold benzene and ether. The content was dried for 4 hours at 105 ^{o}C and weighed (A+B). The content was ashed at 760 ^{o}C for 2 hours and weighed again. The % cellulose was calculated as given by

(Van Soest, 1963).

3.2.1.10 Determination of extractable Phosphorus

An extracting solution of 0.5 M $NaHCO_3$ (sodium bicarbonate), pH 8.5, in a plant-tosolution ratio of 1:10 with 5.0 g of plant sample was shaken for 30 minutes. The concentrations were measured on the Jenway 6051 colorimeter to give absorbance, measurements at a wavelength of 430 nm. A plot of absorbance against concentration was used to prepare the calibration curve. 5 ml of the sample solution was put into a 50 ml volumetric flask. 10 ml of vanadomolybdate reagent was added and volume made up to 50 ml with deionised water. The sample was kept for 30 minutes for colour development. A stable yellow colour was developed. The sample was read on the colorimeter at 430 nm.

The observed absorbance was used to determine the extractable P content from the standard curve. The % extractable P was calculated (Olsen and Sommers 1982).

3.2.2 Formulation and Analysis of Compost and Soil

3.2.2.1 Formulation of co-composting

Formulation of organic materials and poultry manure was carried out with the following the guidelines in Table 3.1

Table 3.1 Formulation of sawdust and rice husk with poultry manure for cocomposting

	Ratio of feedstock to poultry manure		
Feedstock	**(2:1)**	**(3:1)**	**(4:1)**
[1]*Daniellia oliveri* Sawdust (SS)	2SS	3SS	4SS
Daniellia oliveri + [2]*Chrysophyllum albidum* Sawdust (MS)	2MS	3MS	4MS
Rice husk (RH)	2RH	3RH	4RH

Common names: [1]African copaiba balsam tree; [2]White star apple tree

KEY: SS = Sawdust obtained from single species (*Daniellia Oliveri*); MS = Sawdust obtained from mixed species (*Daniellia oliveri + Chrysophyllum albidum*); RH = Rice husk

The feedstock treatment combinations for co-composting shown in Table 1 can be explain as:

T1: 2SS = 2 parts of single species sawdust to 1 part poultry manure

T2: 3SS = 3 parts of single species sawdust to 1 part poultry manure

T3: 4SS = 4 parts of single species sawdust to 1 part poultry manure

T:4 2MS = 2 parts mixed species sawdust to 1 part poultry manure

T5: 3MS = 3 parts mixed species sawdust to 1 part poultry manure T6:

4MS = 4 parts mixed species sawdust to 1 part poultry manure

T7: 2RH = 2 parts rice husk to 1 part poultry manure

T8: 3RH = 3 parts rice husk to 1 part poultry manure

T9: 4RH = 4 parts rice husk to 1 part poultry manure

3.2.2.2 Design of composting bins

The compost bins were constructed as wooden boxes or bins of size 90 cm x 90 cm x 90 cm. The inner part of the bin was lined with 200 µm-plastic films to preserve moisture and heat within the bins. The bins were filled with feedstock according to the treatment plan in Table 3.1.

3.2.2.3 Monitoring the composting process

The qualities of co-compost formulated with the commonly identified materials namely; sawdust, rice husk and poultry litter were studied. During the composting process, temperature (compost and ambient) was taken daily. Compost samples were taken fortnightly for the determination of Moisture, pH, NH^{+}_{4}-N, NO_3^-N, EC, TOC, TN, C/N, CO_2 evolution for a period of 12 weeks. The pH, EC TOC, TN and Ext. P were

determined as described for the feedstock in section 3.2.

3.2.2.3.1 ***Determination of Temperature during composting***

Compost temperature, ambient and substrate temperature was determined in-situ, using a Thermo-couple thermometer (Hanna instruments, HI 935005).

3.2.2.3.2 ***Determination of Volumetric Moisture Content***

Volumetric moisture content (VMC) of compost and substrate were determined in-situ by using a 12 cm rod Hydrosense display unit. To measure the soil moisture content the 12 cm rod Hyrosense display unit was fully inserted into the compost and with a press of READ it displays the measurement result as percent volumetric water content. The period of the probe output is measured in milliseconds. The Hydrosense operating system applies standard calibrations to convert the probe response to volumetric water content.

Campbell Hydrosense moisture meter CS625-L was used to determine the VMC.

3.2.2.3.3 ***Determination of Ammonium- Nitrogen***

A 1.0 g oven-dried sample of each compost replicate was grinded to pass through 0.5 mm sieve and place in 90 mL glass vial extraction vessel. 20 ml deionised water was added and close tightened. The supernatant was then placed in a reciprocating or rotating shaker capable of 250 rpm and shake for 1 hour and centrifuge for 10 minutes at 3000 rpm. The spectrometer was set to 650 nm wavelength. 1 ml of extract/ blank/ standard was transferred into a test tube. 5.5 ml of buffer solution was added and thoroughly mixed. 4 ml of salicylate / nitroprusside solution was added and thoroughly mixed. 2 ml of NaOCl was added and thoroughly mixed. Extract was allowed to stand undisturbed for 45 min at 25^{o}C or 15 min at 37^{o}C. Absorbance was read at 650 nm and NH_4-N calculated (Liu and

Shelp, 1992).

3.2.2.3.4 Determination of Nitrate Nitrogen (NO_3-N) 2 % Acetic Acid Extraction One (1.0) g air-dried compost replicate sample was weighed and placed into 125-mL extraction vessel. Twenty (20) mL 2% Acetic Acid Extraction Solution was added and placed on reciprocating mechanical shaker for 30 minutes a blank was included. The extract was re-filtered and centrifuge for 10 minutes at 3000 rpm. The absorbance on spectrometer was set at 410nm. 1 ml aliquot of the extractant was pipetted into a 50 ml tube and mix thoroughly with 0.8 ml of 5 % salicylic acid in concentrated H_2SO_4. After 20 min, 20 ml of 2 N NaOH was added at reduced temperature to raise pH to 12 (Johnson and Ulrich, 1959; Chapman and Pratt, 1961). Samples were then cooled to room temperature and absorbance measured at 410 nm. NO_3-N in sample was calculated as:

$$\text{mg/kg } NO_3\text{-N} = (\text{analyte conc. mg/L} - \text{method blank}) \times (250)(25)\ \frac{\text{Extraction volume}}{\text{sample wt*dry matter content (\%)/100}}$$

3.2.2.3.5 ***Determination of CO_2 using the alkaline trap method***

A 10 g fresh dry weight of each replicate compost sample was adjusted to 50% moisture, incubated in sealed flasks at 31 C with vials containing 1 N NaOH, (CO_2 trapped). Blanks were also incubated. After 24, 48, and 72 h of incubation, the remaining NaOH was titrated with 0.5 N HCl after addition of excess $BaCl_2$. The following equation was applied: {mg of CO_2= (B-S) x N x E} method by Leconte *et al*., (2009): Where B = mL of acid needed to titrate the NaOH in the blank vials;

S = mL of acid needed to titrate the NaOH in the sample vials;

N = normality of the acid;

E = 22, equivalent weight to express as CO_2.

3.2.2.3.6 *Determination of Particle Size Distribution*

Particle size distribution was estimated by the Bouyoucous hydrometer method, using sodium hexametaphosphate (calgon) as a dispersing agent. A 51.0 g of air dried soil sample was weighed into one-screwed lid shaking bottle (W_T) 100 ml of distilled water was added and the mixture swirled to wet the soil thoroughly. 20 ml of 30 % H_2O_2 was added to destroy soil organic matter, freeing the individual classes of soil 50 ml of 5 % of sodium hexametaphosphate solution was added more drops of amyl alcohol, 95 % was added and gently swirled to minimize foaming. The content was shaken on mechanical shaker for 2 hr. The content was transferred into a 1000 ml sedimentation cylinder. Water washed soil particles was added to the sedimentation tube. Distilled water was added to make up to the 1000 ml mark. The first hydrometer and temperature readings were taken after 40 seconds. The sample was allowed to stand for 3 hours and the second hydrometer and temperature readings recorded afterwards.

3.2.2.3.7 *Production of biochar*

Biochar was produced following the method of JIRCAS, (2014). A 0.5 kg of starter wood materials was set on fire and the naked fire covered with the Japan retort stove (tradeName: Kuntan apparatus). An amount of 20 kg of feedstock was heaped around the base of the stove. The feedstock was turned every 10 minutes to ensure uniform charring.

The charring temperature was maintained at 250-300 ˚C for 1 hour.

3.3. EXPERIMENTATION-CROP RESPONSE TO COMPOST AND BIOCHAR

Following the characterisation and composting of feedstock the following experiments were conducted to evaluate the resulting compost as standard amendments in soil and soilless production systems.

3.3.1 Pot Experiments

3.3.1.1 Experiment One: Evaluation of compost and compost biochar mixes for Lettuce and ornamental African marigold production

Experimental design, treatments and procedure: Each of the nine compost was mixed with top soil in the ratio of 2 parts of compost to 3 parts of topsoil. The nine compost and a control as indicated below treatments were set up in completely randomised design (CRD) with 4 replications.

1. 2-2SS3T = 2 parts 2SS + 3 parts topsoil
2. 2-3SS3T = 2 parts 3SS + 3 parts topsoil
3. 2-4SS3T = 2 parts 4SS + 3 parts topsoil
4. 2-2MS3T = 2 parts 2MS + 3 parts top soil
5. 2-3MS3T = 2 parts 3MS + 3 parts top soil
6. 2-4MS3T = 2 parts 4MS + 3 parts top soil
7. 2-2RH3T = 2 parts 2RH + 3 parts top soil
8. 2-3RH3T = 2 parts 3RH + 3 parts top soil
9. 2-4RH3T = 2 parts 4RH + 3 parts top soil
10. Top soil without compost (Control)

Pots used had dimensions of 25/20 cm (diameter/height). This means the soil occupied 12 cm of the height of the pot and the compost occupied the rest of the 8 cm height.Great lake variety of Lettuce was nursed and transplanted three weeks after nursing. Watering was done every two days or when media conditions suggest the topsoil is drying. No pesticide was applied because of the protected environment. Data collected were plant height, number of leaves, leaf chlorophyll content, fresh and dry weight of leaves.

- Plant height was measured in cm from soil level to shoot tip using a ruler, 3 times at 2 weekly interval at 2, 4 and 6 weeks after transplanting (WAT)
- Number of leaves were counted 3 times at two weekly interval as plant height
- The chlorophyll content of the leaves was measured by inserting a leaf into the sample slot of the measuring head. The finger rest was pressed and held until the beep sound noticed and the SPAD values appeared. The SPAD value was used as the index of chlorophyll content. Relative chlorophyll content {Soil Plant Analysis Development (SPAD)} was measured every two weeks using a Minolta chlorophyll meter (model SPAD 502).
- Fresh and dry weight of all leaves per plant were measured using an electronic balance

In a related second study, the 2SS and 2MS compost were selected as N sources based on nutrient content of the compost and mixed with rice husk biochar to amend soils for marigold production. Each of the compost (2SS and 2MS) was mixed with various proportion of rice husk biochar in proportions and the resulting mixtures used to amend a fixed volume of 3 parts of topsoil in each case to obtain the following treatments:

1. 2-2SS3T = 2 parts 2SS + 3 parts topsoil + biochar

2. 2-2SS3TB = 2 parts 2SS + 3 parts topsoil + 1 part biochar
3. 2-2SS3T2B = 2 parts 2SS + 3 parts topsoil + 2 parts biochar
4. 2-2SS3T3B = 2 parts 2SS + 3 parts topsoil + 3 parts biochar
5. 2-2SS3T4B = 2 parts 2SS + 3 parts topsoil + 4 parts biochar
6. 2-2MS3T = 2 parts 2MS + 3 parts topsoil + biochar
7. 2-2MS3TB 2 parts 2MS + 3 parts topsoil + 1 part biochar
8. 2-2MS3T2B = 2 parts 2MS + 3 parts topsoil + 2 parts biochar
9. 2-2MS3T3B = 2 parts 2MS + 3 parts topsoil + 3 parts biochar
10. 2-2MS3T4B = 2 parts 2MS + 3 parts topsoil + 4 parts biochar

The planting pots used had dimensions of 25/20 cm (diameter/height). African marigold was nursed and transplanted three weeks after nursing. Watering was done every two days or when media conditions suggest the topsoil is drying. No pesticide was applied because of the protected environment. Plant height, number of leaves, leaf chlorophyll content and number of flowers per plant were also determined.

3.3.1.2 Experiment Two - Evaluation compost-topsoil mixes as media for the production of Lettuce and Zinnia

Experimental design, treatments and procedure

Based on the nutrient content, the 2SS, 2MS and 2RH composts were selected and used to amend soil in the ratios of 1:1, 1:2 and 1:3 (compost:soil- v/v). The characteristics of the soil used are given in Table 1a. The three compost types were set up at three volumetric ratio of soil to compost in completely randomized design with four replications. A pot without amendment was set up to serve as control. The treatments were as follows:

1. 1-2SST = 1 part 2SS + 1 part topsoil
2. 1-2SS2T = 1 part 2SS + 2 parts topsoil
3. 1-2SS3T = 1 part 2SS + 3 parts topsoil
4. 1-2MST = 1 part 2MS + 1 part topsoil
5. 1-2MS2T = 1 part 2MS + 2 parts topsoil
6. 1-2MS3T = 1 part 2MS + 3 parts topsoil
7. 1-2RHT = 1 part 2RH + 1 part topsoil
8. 1-2RH2T = 1 part 2RH + 2 parts topsoil
9. 1-2RH3T = 1 part 2RH + 3 parts topsoil
10. Top soil without compost (Control)

Pots used had dimensions of 25/20 cm (diameter/height). Great lake variety of Lettuce and Zinnia elegans were nursed and transplanted three weeks after nursing. Watering was done every two days or when media conditions suggest the topsoil is drying. No pesticide was applied because of the protected environment. The data collected on lettuce were number of leaves, chlorophyll content and final fresh & dry weight of biomass. These were measured or determined as specified in Experiment One. Substrate temperature and moisture were determined following the procedure specified in section 3.2.2.2.1 and 3.2.2.2.3 respectively.

The data collected on Zinnia included plant height, stem girth, number of leaves, chlorophyll content (as SPAD value), substrate moisture and temperature levels, number of flowers, flower head diameter, flower head weight, flower stalk length and final fresh & dry weight of biomass. Determination of plant height, leaf number, chlorophyll content, fresh & dry weight of biomass was as specified in Experiment One. Number of flowers was determined as specified in Experiment Two. Stem girth, flower head diameter and flower stalk length were measured using electronic vernier calipers. Flower head weight was measured using a portable electronic balance.

3.3.1.3 Experiment Three – Evaluation of the response of lettuce and ornamental Zinnia to soilless media and irrigation

Experimental design, treatment and procedure

The 2SS and 2RH were selected (based on the nutrient analysis) and mixed with rice husk biochar at ratios of 1:0, 1:1 and 1:2 (compost-biochar, v/v) as soilless substrate for lettuce and Zinnia production. Each of the compost-biochar mixes was further subjected to two irrigation regimes. This arrangement gave a 6 x 2 (compost-biochar mix x irrigation) factorial with 4 replicates in CRD.

Treatments were as follows:

1 2SS x Irrigation I = 2SS compost without Rice husk biochar, x 0.1125 mm irrigation

2 2SS x Irrigation II = 2SS compost without Rice husk biochar, x 0.225 mm irrigation

3 1-2SSRB x Irrigation I = 1 part 2SS + 1 part Rice husk biochar x 0.1125 mm irrigation

4 1-2SSRB x Irrigation II = 1 part 2SS + 1 part Rice husk biochar x 0.225 mm irrigation

5 1-2SS2RB x Irrigation I = 1 part 2SS + 2 parts Rice husk biochar x 0.1125 mm irrigation

6 1-2SS2RB x Irrigation II = 1 part 2SS + 2 parts Rice husk biochar x 0.225 mm irrigation

7 2RH x Irrigation I = 2RH compost without Rice husk biochar, x 0.1125 mm irrigation

8 2RH x Irrigation II = 2RH compost without Rice husk biochar, x 0.225 mm irrigation

9 1-2RHRB x Irrigation I = 1 part RH + 1 part Rice husk biochar x 0.1125 mm

10 1-2RHRB x Irrigation II = 1 part 2RH + 1 part Rice husk biochar x 0.225 mm irrigation

11 1-2RH2RB x Irrigation I = 1 part 2RH + 2 parts Rice husk biochar x 0.1125 mm irrigation

12 1-2RH2RB x Irrigation II = 1 part 2RH + 2 parts Rice husk biochar x 0.225 mm irrigation

All pots were watered on the first day to a VMC between 50 and 60 %. Subsequently, for irrigation I, amount of water applied per day was 0.1125 mm for 20 times. For irrigation II, amount of amount of water applied per day was 0.225 mm for 20 times. Pots used had dimensions of 25/20 cm (diameter/height). Data collected on Lettuce were number of leaves, chlorophyll content (as SPAD value), substrate moisture and temperature levels and finally fresh & dry weight of biomass. The parameters were measured as specified in Experiment Two.

Data collected on Zinnia were plant height, stem girth, number of leaves, chlorophyll content (as SPAD value), substrate moisture and temperature levels, number of flowers, flower head diameter, flower head weight, flower stalk length and finally fresh & dry weight of biomass. Determination of plant height, leaf number, chlorophyll content, fresh & dry weight of biomass was as specified in Experiment Two. Number of flowers was determined as specified in Experiment Two. Stem girth, flower head diameter and flower stalk length were measured using electronic venier calipers. Flower head weight was measured using a portable electronic balance

3.3.2 Field Experiment

3.3.2.1 Experiment Four - Evaluation of compost-biochar mixes as amendment for field production of *Amaranthus*

Experimental design, treatment and procedure

Treatments consisted of sawdust compost and rice husk compost mixed with rice husk biochar or sawdust biochar, including a control plot with no amendment. There were seven treatment set up in RCBD with four replications. Plot size was 1m x 1m.

The treatments included:

1. 2SS+SSB = 2SSB compost (10 ton ha^{-1}) + sawdust biochar (5 ton ha^{-1})
2. 2SS+RHB = 2SS compost (10 ton ha^{-1}) + rice husk biochar (5 ton ha^{-1})
3. 2RH+RHB = Rice husk compost (10 ton ha^{-1}) + rice husk biochar (5 ton ha^{-1})
4. 2RH+SSB = Rice husk compost (10 ton ha^{-1}) + sawdust biochar (5 ton ha^{-1})
5. 2SS = 2SS compost only (10 ton ha^{-1})
6. 2RH = Rice husk compost only (10 ton ha^{-1})
7. Control (no amendment)

Amaranthus seeds were drilled in rows and subsequently thinned to one plant per stand at two weeks after nursing. Distances between plants were kept at 15 cm x 15 cm. for characteristics of the treatment refer to Table 4.3 and Table 4.6. The data collected included plant height, number of leaves, leaf chlorophyll content, fresh and dry weight of leaves (for the measurement of these parameters refer to Experiment One). The leaf area was determined using the linear equation described by Olasantan, and Salau (2008) as follows Y = -1.45 + 0.65 (L x B); Y = leaf area (cm), L = Length of leaf (cm) and B = Breadth of the leaf (

3.3.3 Greenhouse Production

3.3.1 Experiment Five: Evaluation of compost-biochar mixes as soilless media for greenhouse production of sweet pepper and runner beans

Objective**:** to determine the effect of soilless media on the growth and fruit yield of sweet pepper (fruit vegetable) and runner beans (pod vegetable)

Experimental design, treatment and procedure

Sawdust compost and rice husk compost were each mixed with rice husk biochar and sawdust biochar. A control treatment (a commercially recommended soilless) was added to give 5 treatments set up in a completely randomized design (CRD) with four replications. The treatments included the following:

1. 2SS+SSB = 2SSB compost + sawdust biochar
2. 2SS+RHB = 2SS compost + rice husk biochar
3. 2RH+RHB = Rice husk compost + rice husk biochar
4. 2RH+SSB = Rice husk compost + sawdust biochar
5. Coir soilless media as Control

**Compost - biochar mixes was in the ratio of 1:2 for treatment 1, 2, 3 and 4.*

The coir used as control was purchased from DIZENGOFF Ghana limited. The coir was fed with nutrient concentration based on DIZENGOFF protocol. Watering was done as and when needed. No pesticide was applied because of the protected environment. The data collected for sweet pepper were plant height, number of leaves, number of flowers (refer to Experiment One and Two for the measurement of these parameters). Stem girth was measured as specified in Experiment three. Number of fruits was counted and fresh fruit weight measured using a portable electronic balance. The data collected on runner beans were plant height, number of leaves (parameters were measured as specified in Experiment One and Two). Stem girth was measured as specified in Experiment Four. Number of fruits was counted and fresh fruit weight measured using a portable electronic balance. The average temperature in the greenhouse was 27 °C and the relative humidity was 85 %. The roof was designed to allow in full sunlight.

3.4 DATA ANALYSIS

Data collected from the survey analysed using Statistical Package for the Social Sciences version 17 (SPSS V.17). Logistic regressions and chi-square statistics were performd on the survey data. Data obtained from the experiments and laboratory analyses were subjected to analysis of variance using Genstat version 9. Treatment means were separated using least significant difference (LSD) at 5% level of probability. Correlation and regression analysis were performed on maturity and stability indices of compost.

CHAPTER FOUR

4.0 RESULTS 4.1

SURVEY STUDY

4.1.1 Profile of Urban Horticultural Practitioners

In Tamale, about 67 % of practitioners had no formal education and 33 % had at least nine years of education (elementary level). In Kumasi, 40 % of horticultural practitioners had no formal education and 60 % had at least nine years of education. About 44 % of practitioners in Tamale were male and 56 % were female. In Kumasi, 74 % of practitioners were male and 26 % were female. About 70 % of practitioners in Kumasi were within the age range of 20-40 years and 30 % were above 40 years. In Tamale however, only 26 % were within the age range of 20-40 years and 74 % were above 40 Years.

4.1.2 Farmer Knowledge of Availability of Common Soil Amendment

The common amendments identified were compost, cow manure, refuse soil, sawdust and rice husk. Comparing the two locations, a significantly ($p < 0.05$) greater percentage of farmers in Kumasi than in Tamale had knowledge of the use of compost, refuse soil and sawdust. For cow manure, however, a significantly greater percentage of farmers in Tamale than in Kumasi had knowledge of its use (Table 4.1). The knowledge level of farmers in both locations was similar for rice husk. Within the Tamale location, only cow manure was known by majority of farmers. Most farmers had no knowledge of the use the rest of the amendments. Within Kumasi, however, all the amendments were known by a majority of farmers, except for rice husk where majority of the farmers did not know of its use as an amendment (Table 4.1).

Table 4.1: Urban farmers' awareness of proper use of different organic manures

Organic material	Awareness	District response (%)		Chi-square value	p-value
		Tamale	Kumasi		
Compost	Yes	50.0	83.3	7.5	0.006
	No	50.0	16.7		
Cow manure	Yes	86.7	53.3	7.937	0.005
	No	13.3	46.7		
Refuse soil	Yes	3.3	66.7	26.447	0.001
	No	96.7	33.3		
Black soil	Yes	36.7	100	27.805	0.001
	No	63.3	0.0		
Sawdust	Yes	26.7	100	34.737	0.001
	No	73.3	0.0		
Rice husk	Yes	36.7	40.0	0.071	0.791
	No	63.3	60.0		

4.1.3 Adoption of Common Soil Amendments

The percentage of urban farmers that adopted cow manure in Tamale was 60 %, significantly ($p= 0.001$) greater than the percentage that adopted in Kumasi (3 %) (Table 4.2). On the other hand, a significantly ($p=0.005$) greater percentage of urban farmers in Kumasi (93 %) adopted poultry manure as compared to the percentage in Tamale (63 %). A strong, positive and significant correlation was found between farmers experimenting with amendments and those actually adopting the use of the amendments ($r = 0.79$; $p <0.001$; $n = 60$).

Table 4.2: Responses (%) on adoption of organic manure by urban farmers (n=60)

District	Organic material			
	Cowdung		Poultry manure	
	Yes	No	Yes	No
Tamale	60	40	63.3	36.7
Kumasi	96.7	3.3	93.3	6.7
X^2 – value	22.259		7.954	
p-value	0.001		0.005	

4.1.4 Reasons for Using Particular Amendments

Fifty-six percent of farmers who were using poultry manure believe poultry manure has better quality and lasting effect on soil compared to inorganic fertilizers. Judging the strength of soil amendments, 63 % of farmers noticed better growth in plants and 21 % noticed good soil properties. About 16 % did not observe any difference. Twenty eight percent observed that poor or variable quality of soil amendments is a major weakness. It was observed that composted sawdust composted crop residues and cow manure were the dominants amendments, but because they were the most widely available materials and had good properties for crop growth

4.1.5 Challenges of Preparing, Obtaining and Applying Soil Amendments

Sixty percent of farmers organise or prepare amendment themselves, 31% of them were supplied by decentralised soil amendment producers. Fifty-eight percent of farmers in both Tamale and Kumasi, obtained soil amendment within 1-15 km radius of their farms and 35% of other farmers in Tamale and Kumasi obtained soil amendment within 16-30 km radius of their farms. About 7 % did not provide answers. Most farmers applied between ½ and 1 bag (12.5-25 kg) per bed (72 m^2). This is equivalent to 1.7 to 3.4 ton ha^{-1}. About 90 % of farmers use bicycles or "motor-king" (motor tricycle with trailers) to transport amendment to the farm. As farmers are already familiar with sawdust based poultry litter, the co-composting of sawdust would be the best option that can be developed and standardised for application in urban horticulture. The outcome of the survey informed the basis of the choice of feedstock for further study to standardize the preparation protocol and characterize the end product.

4.2 EXPERIMENTAL STUDIES

4.2.1 Characterisation, Formulation and Analysis of Feedstock, Compost and Soil

4.2.1.1 Characterisation of compost feedstock

Poultry manure as compared to the other amendments, was significantly higher ($p=0.017$) in N (4.37 %), P (1.05 %), ($p=0.044$), K (4.10 %); $p=0.030$, Ca (4.47 %); $p=0.010$, Mg (3.1 %); $p=0.002$ and higher in density (0.5 g/cm^3); $p=0.003$. For the other parameters, all feedstock had similar nutrient content. The mixed species (MS) sawdust was highest in moisture content (12.1 %); $p=0.001$, total organic carbon (TOC) (45.1 %); $p<0.001$, cellulose (42.1 %); p<0.001 and lignin (23.7 %); p=0.040. Single species (SS) sawdust was highest in electrical conductivity (EC) (8.7 mS/cm^3); p=0.001.

Table 4.3: Physico-chemical properties of feedstock

Properties	Poultry manure	Rice husk	SS Sawdust	MS Sawdust	LSD	p-value
N (%)	4.37	0.38	0.25	0.41	0.085	0.017
P (%)	1.05	0.43	0.21	0.15	0.015	0.044
K (%)	4.10	1.81	1.34	0.72	0.0925	0.030
Ca (%)	4.47	0.82	1.26	1.32	0.060	0.010
Mg (%)	3.19	0.73	0.91	0.66	0.0275	0.002
Moisture (%)	9.45	7.10	11.30	12.13	0.550	0.001
EC (mS/cm^3)	4.00	3.55	8.73	3.41	0.230	0.001
Density (g/cm^3)	0.50	0.25	0.28	0.25	0.015	0.003
TOC (%)	25.40	40.37	42.50	45.18	1.082	<0.001
Cellulose (%)	23.87	27.74	32.75	42.11	0.0925	<0.001
Lignin (%)	11.77	21.68	23.15	23.74	0.225	0.040

The soil used for the experiment was sandy loam and slightly acidic. The level of N was very low (0.06 %). Low C/N ratio (10.15±0.71), low organic matter contents (as indicated by organic carbon level of 58%) and low P values were observed (Table 4.4).

Table 4.4: Properties of the soil used for the experiment

pH (CaCl2)	C (%)	N(%)	P(mg/kg)	C/N	Sand (63-2000µm)	Silt (2-63µm)	Clay (<2µm)
5.22±0.15	0.58±0.08	0.06±0.01	3.79±0.04	10.15±0.71	34.17±4.40	58.88±4.55	6.58±0.19

4.2.1.2 Temperature profile of compost from start to maturity

The 2SS and 3SS maintained temperature above 40°C (thermophilic temperature) for one week before falling below 40°C (mesophilic). The 4SS could only maintain the temperature for four days. Turning the compost resulted in increasing the temperature to 43°C. The highest peak temperature (51°C) was attained in 2SS compost at 43 days and 50°C for 4SS at 41 days. After 43 days, the temperature dropped below 40°C and close to ambient temperature of 35°C (Figure 4.1).

In the mixed sawdust compost, temperature rose to 41°C overnight for 2MS and 4MS. Within the same period, temperature in the 3MS compost rose to 45°C. These temperatures were maintained for three days before falling to values below 40°C. After turning the compost at one week, the temperature fluctuated between thermophilic and mesophilic states until it fell to ambient temperature levels at day 43. Turning the compost at this stage increased temperatures to 49°C for 3MS and 50°C for 4MS. There was a sharp drop in temperature to ambient levels in all three mixed sawdust compost (Figure 4.2).

In all the rice husk compost, temperatures rose above 40°C within 24 hr. of composting. Between 3 and 8 days, the 3MS attained the highest temperature of 47°C. At 33 days, temperature in all the ratios fell to ambient levels. After 33 days, the 2SS attained peak temperature of 45-48°C and maintained this range of temperature for 5 days (Figure 4.3).

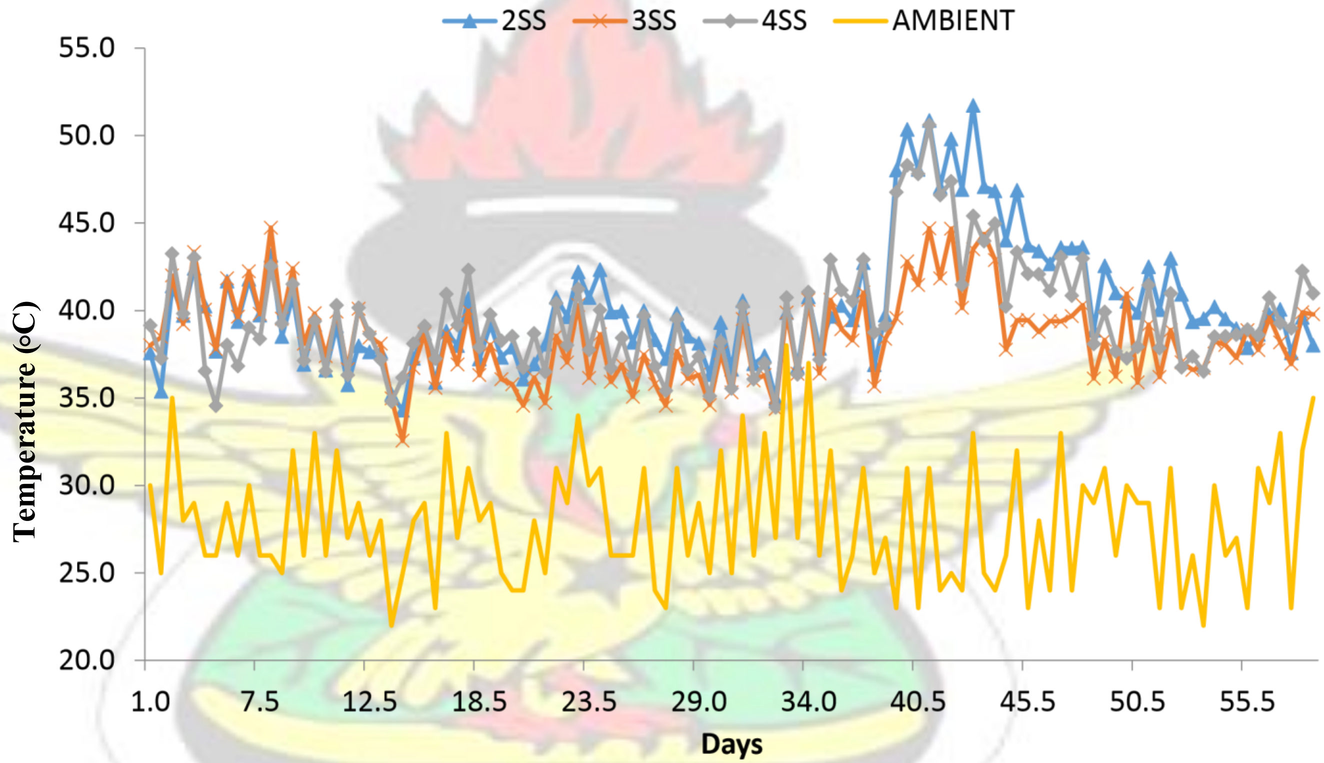

Figure 4.1: Temperature profile of SINGLE species sawdust feedstock to poultry manure

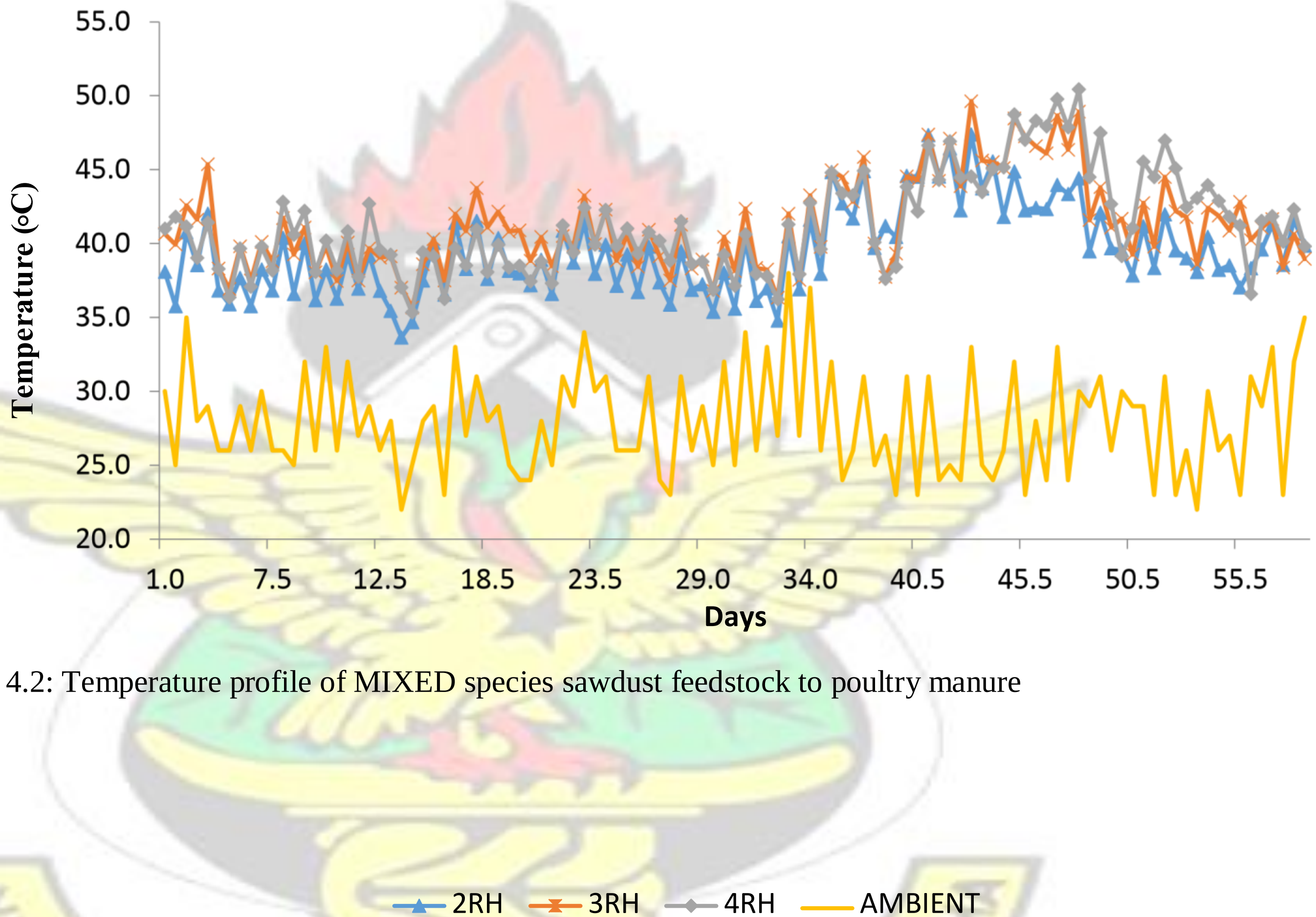

Figure 4.2: Temperature profile of MIXED species sawdust feedstock to poultry manure

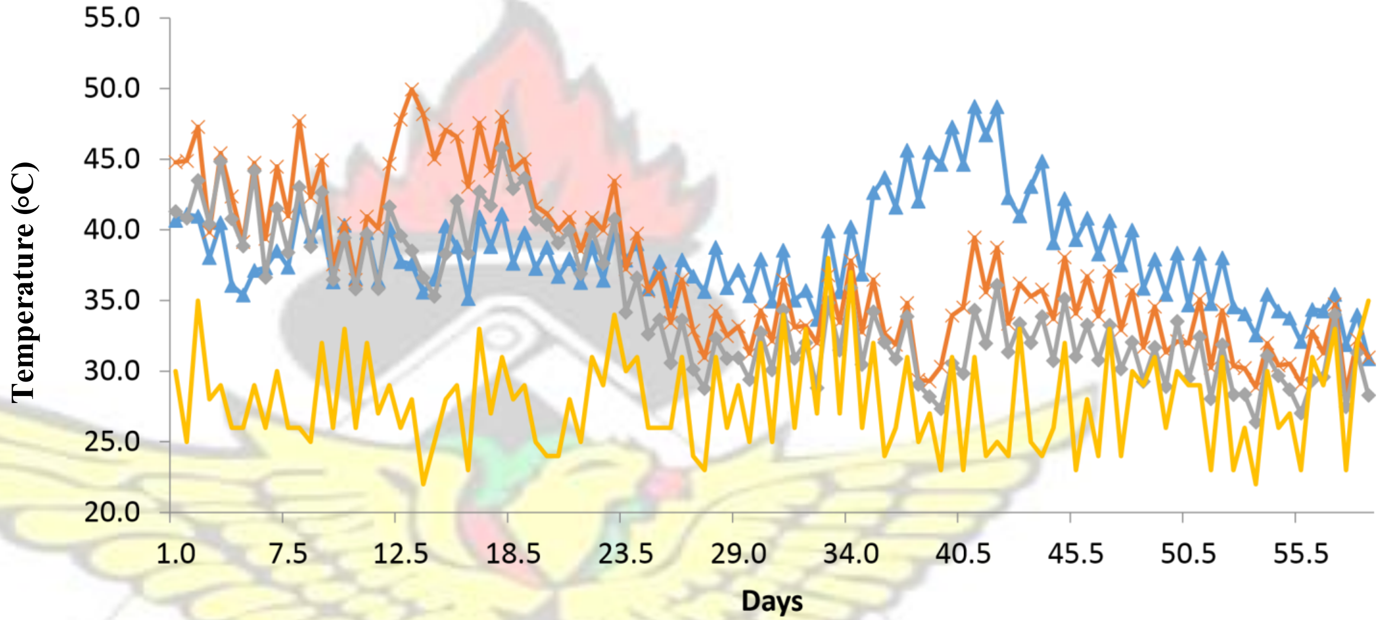

Figure 4.3: Compost temperature as affected by ratio of rice husk to poultry manure

4.2.1.3 CO_2 evolution of compost from start to maturity

The CO_2 evolution was similar for all treatments. At the start of composting, CO_2 level range from 100-129 mg/kg/h. The CO_2 level rose significantly to 268.5 mg/kg/h at 2 weeks of composting. At 4 weeks CO_2 increased slightly (but significant) to 306.1 mg/kg/h and declined significantly to values between 84.95 and 116.47 mg/kg/h. When the compost was turned for curing at 12 weeks the CO_2 increased (not significant) slightly especially 4MS compost (Figure 4.4).

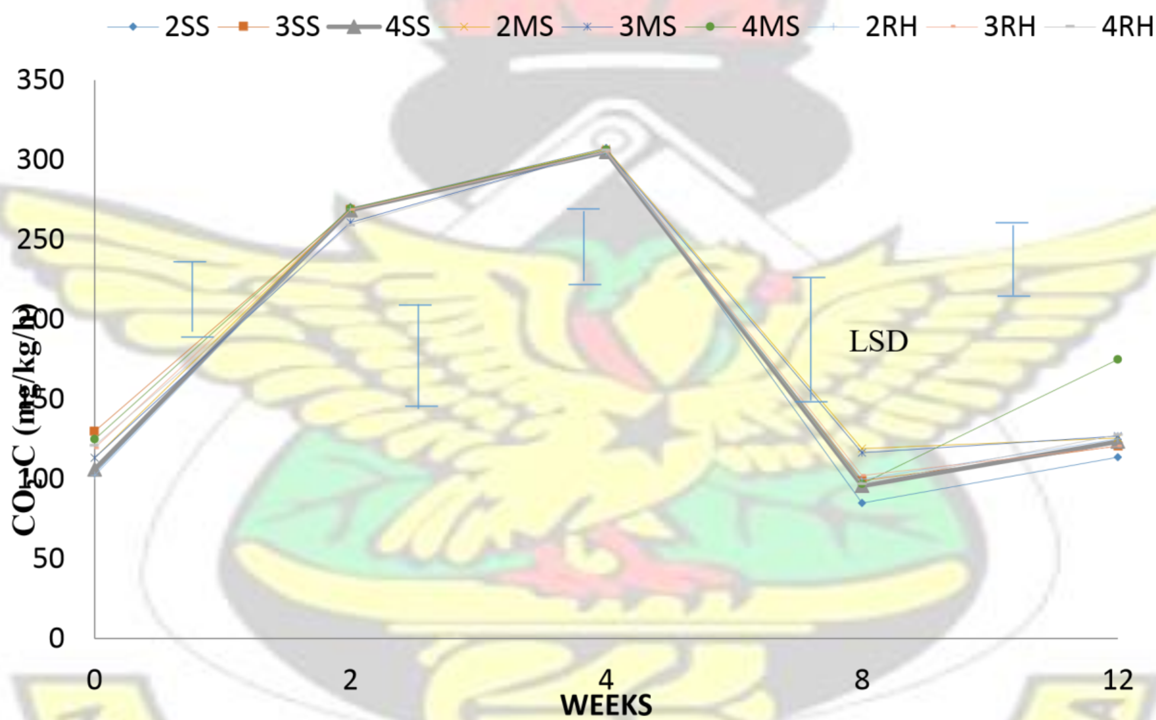

Figure 4.4: CO_2 content as affected by ratio of sawdust and rice husk feedstock to poultry manure (bar on graph = LSD- 0.05).

4.2.1.4 Changes in pH

At the start of composting, the pH of 4MS (pH of 8.8), 2MS and 3MS (each having pH of 8.5) were highly alkaline and the 2SS (pH of 7.8) was slightly alkaline. At 2 weeks of composting, pH values dropped to values ranging from neutral in 3MS compost (pH value of 7.0) to slightly acidic in 4SS compost (pH of 6.5). There were no significant differences in pH values between 2 and 6 weeks of composting. At 8-12 weeks, the 3MS and 4MS had neutral pH significantly higher than all other treatments. The 3RH, 4RH and 2MS were slightly acidic, with pH (6.8) significantly lower than all other treatments (Figure 4.5).

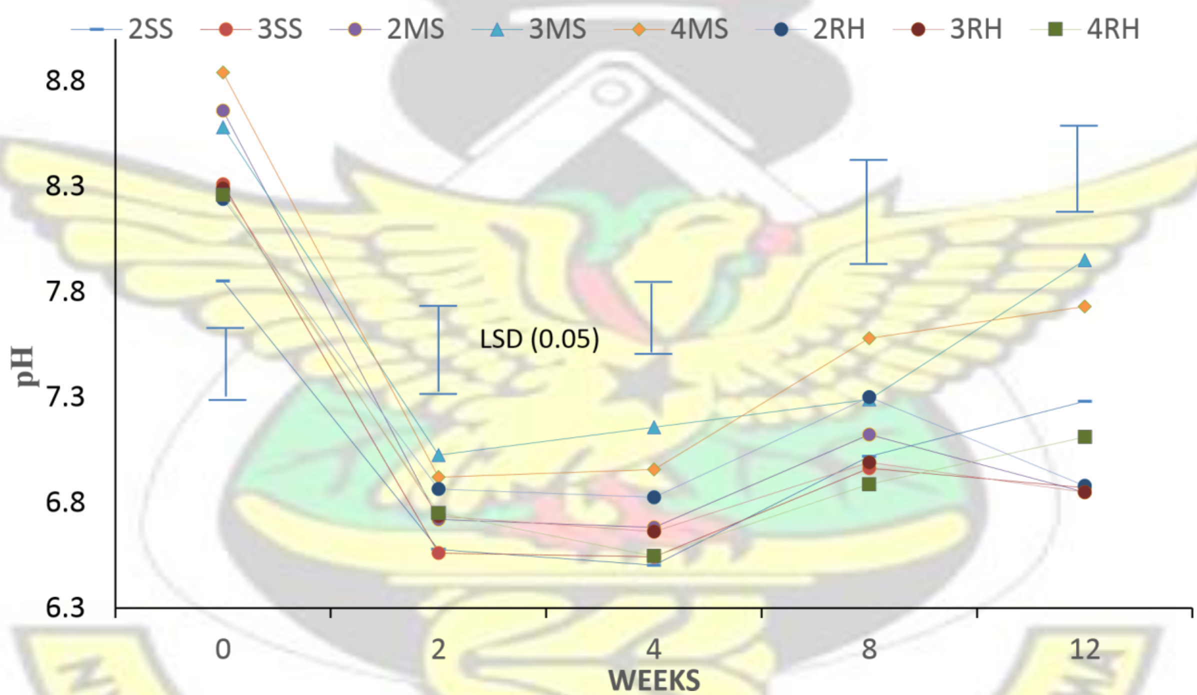

Figure 4.5: pH profile of compost as affected by ratio of sawdust and rice husk to poultry manure (bars on graph = LSD at 0.05 %)

4.2.1.5 Dynamics in electrical conductivity

At the start of composting of the single species, the 2SS compost had the highest EC of 3.9, significantly greater than 3SS and 4SS, which had the least ECs of 2.7 and 2.2, respectively (Figure 4.6). After 2 weeks of composting, all three single species sawdust composts had similar ECs. After 4 weeks of composting however, 4SS had significantly higher EC than 3SS which had the lowest. Showing consistency, after 8 weeks of composting, 4SS continued to have the highest EC, significantly greater than those of 2SS and 3SS. However, at 12 weeks of composting, all three single species sawdust composts recorded similar ECs (Figure 4.6).

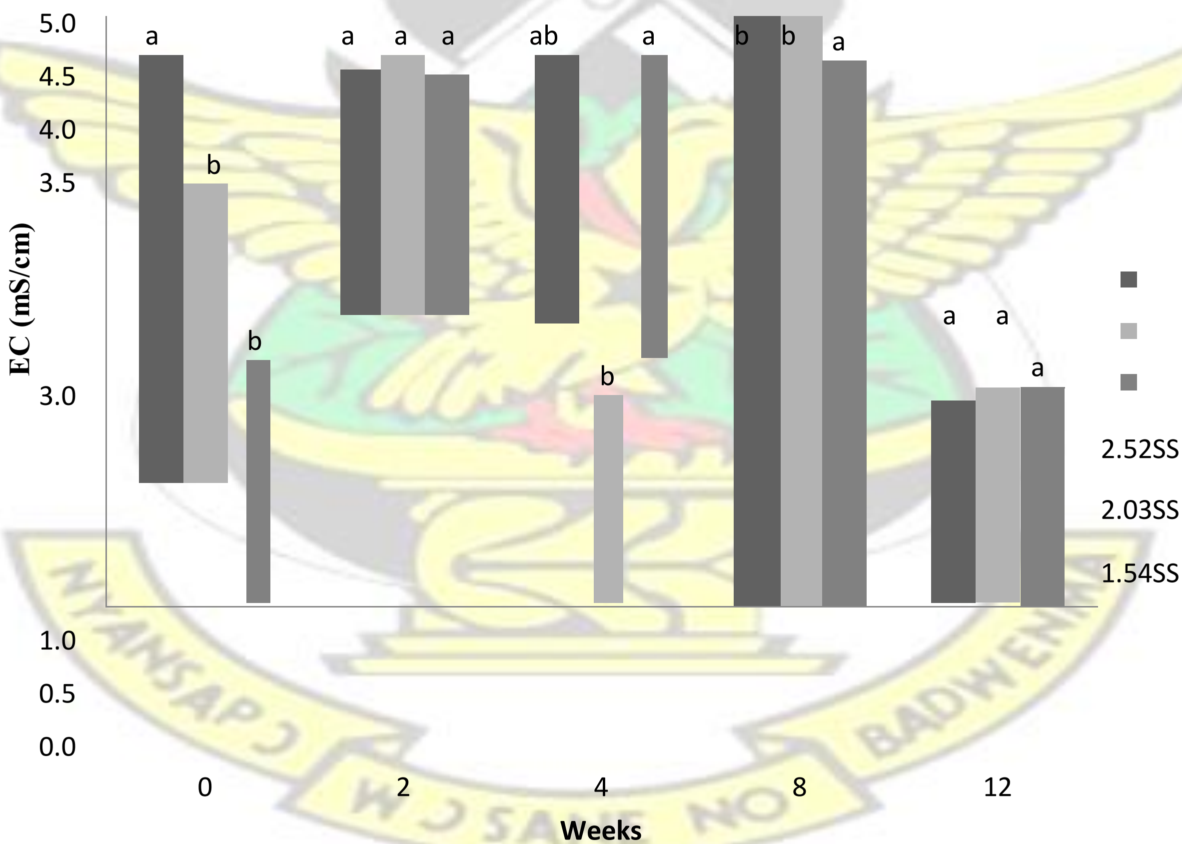

Figure 4.6: Electrical conductivity profile of compost from single species sawdust

From the start of composting till 2 weeks of composting, all the three mixed species compost had similar ECs. After 4 and 8 weeks of composting, the 2MS and 3MS compost had significantly higher than the 4MS compost which had EC value of 1.7 mS/cm^3. However, after 12 weeks of composting, all three mix species sawdust had similar EC values (Figure 4.7).

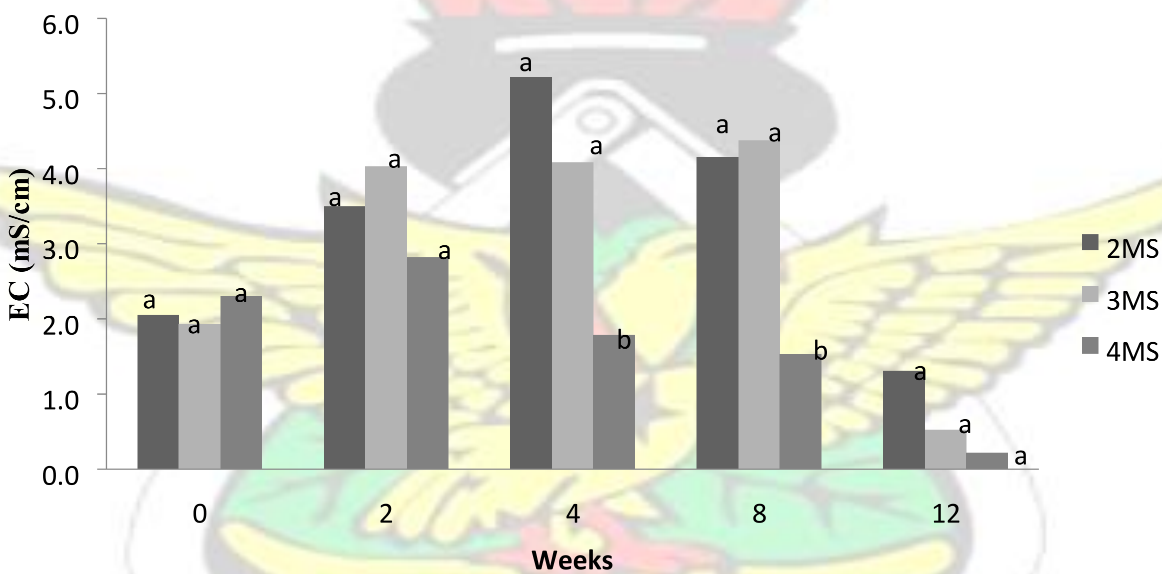

Figure 4.7: Electrical conductivity profile of compost mixed species sawdust

At the start of composting, the 2RH had EC of 3.9 significantly higher than 3RH and 4RH with ECs of 2.9 and 2.8 respectively. After 2 and 4 weeks of composting, the 2RH and 3RH had significantly lower EC than 4RH. However, at 8 weeks and 12 weeks of composting, all the three rice husk composts had similar ECs (Figure 4.8).

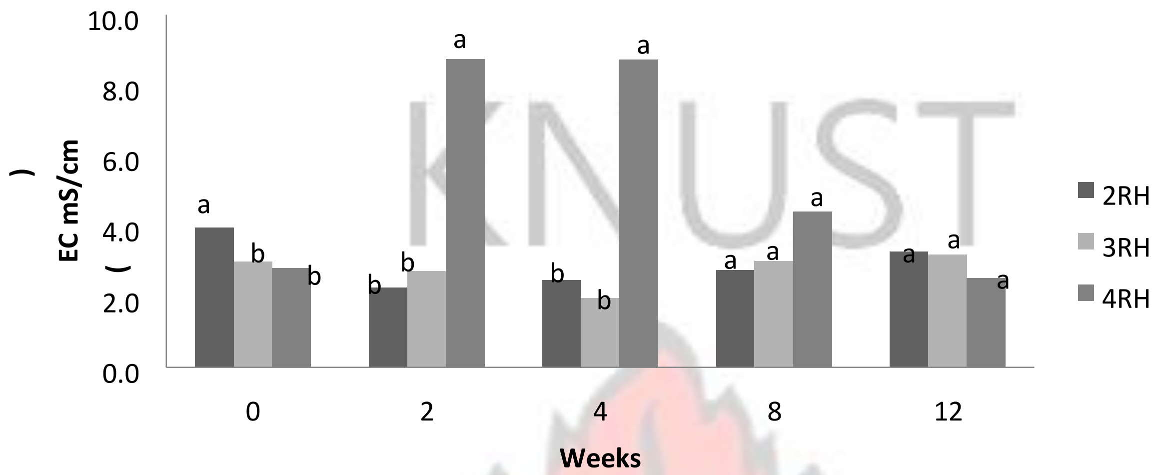

Figure 4.8: Electrical conductivity profile of compost from rice husk

4.2.1.6 Stability and maturity indices of the mature compost

The C:N ratio is an important measure of stability and hence maturity of compost. At 4 weeks of composting, 4MS recorded the highest C:N ratio value, significantly greater than the rest of the composts, except that of 3 MS which was similar. The least C:N ratio was recorded by 2RH compost. At 8 weeks of composting, 4MS continued to record the highest C:N ratio value, significantly greater than all the other composts. The least C:N ratio was still recorded by 2 RH. However, at 12 weeks of composting, 4RH had the highest C:N ratio value, significantly greater than the rest of the composts. The least C:N ratio was recorded by 2SS (Table 4.5). In comparison to the EU standard, all the compost types at 12 weeks of compost had attained maturity, except 4RH which had C:N ratio value still above the standard (Table 4.5).

Table 4.5: C:N value as affected by age of composting

Compost type	C:N ratio		
	4 weeks	**8 weeks**	**12 weeks**
2SS	29.69	24.55	15.76
3SS	32.48	30.45	18.83
4SS	31.22	28.50	20.25
2MS	30.15	29.34	22.50
3MS	40.74	30.69	20.79
4MS	43.38	36.00	20.83
2RH	26.43	24.25	19.31
3RH	28.08	27.73	20.44
4RH	32.33	33.18	26.23
p-value	0.005	0.030	<0.001
LSD (0.05)	5.166	3.81	3.43
EU C:N ratio standard for mature compost (Sæbøa and Ferrini, 2006)		15- 25	

4.2.1.7 Compost quality

The 2SS compost recorded significantly the highest total nitrogen content (2.45 %), whereas the 4RH gave the least (1.3 %). The 2MS recorded the highest carbon content (41 %), while the 4RH had the lowest carbon content (33.28 %). The NH_4-N level was highest in 2MS (214.98 mg/kg) and lowest in 4SS (23.45 mg/kg). The 2SS recorded the lowest C:N value (15: 1) whereas the 4RH recorded the highest C:N value of 26:1. The pH value was highest in 3MS compost and lowest in 2MS, 2RH, 3SS and 3RH each with pH value of 6.85. The 2SS had the highest EC of 1.87 mS/cm^3 whereas 4MS had the lowest EC value of 0.22 mS/cm3 (Table 4.6)

Table 4.6: Summary of quality indices of the mature composts at 12 weeks of composting

COMPOST	Total N	Organic C (%)	NH_4-N (mg/kg)	C:N	pH	EC (mS/cm^3)
2SS	2.46	38.40	38.28	15.76	7.28	1.87
2MS	1.82	39.62	215.98	22.50	6.85	1.31
2RH	1.68	35.66	76.45	19.31	6.85	0.33
3SS	2.11	39.31	38.8	18.83	6.85	1.99
3MS	2.02	41.05	81.16	20.79	7.95	0.52
3RH	1.61	31.88	163.94	20.44	6.85	0.58
4SS	2.04	40.99	23.45	20.25	7.11	1.59
4MS	2.02	40.90	102.91	20.83	7.73	0.22
4RH	1.32	33.28	212.78	26.23	7.11	0.86
p-value	0.003	0.001	0.006	<0.001	0.034	0.002
LSD (0.05)	0.188	2.062	3.37	3.43	0.084	0.054
EU standard*	-	-	<500	15-25	6-8	0-4

*** Sæbøa and Ferrini, 2006**

4.2.1.8 Relationship between maturity indices and maturation during composting In general, total nitrogen was differentially related to the C:N content of the compost depending on the base material of the compost. For single species sawdust compost, total nitrogen accounted for 93 % of the variation in the C:N content of the compost in the relationship; $Y_{(C/N)} = 50.099 – 14.502 X_{(TN)}$; $R^2 = 0.93$; p = <0.001 ; n = 40). However, for mixed species sawdust compost, total nitrogen explained 87 % of the variation in the C:N content of the compost in the relationship; $Y_{(C/N)} = 58.455 – 19.541 X_{(TN)}$; $R^2 = 0.87$; p =<0.001 ; n = 40).

Total nitrogen explained 77 % of the variation in the C:N content of the rice husk compost in the relationship; $Y_{(C/N)} = 47.126 – 16.795 X_{(TN)}$; $R^2 = 0.77$; p =<0.001; n = 40).

In terms of associative relationships, for single species sawdust compost, the following correlations were found; Total nitrogen and pH (r= -0.80, p<0.001, n = 40)(Appendix 2); Total nitrogen and C:N (r= -0.96, p<0.001, n = 40); Total nitrogen and CO_2 (r= -0.83, p<0.001, n = 40) and CO_2 and pH (r= -0.91, p<0.001, n = 40). For mixed species sawdust compost, the following correlations were found; Total nitrogen and pH (r= 0.567, p<0.001, n = 40); Total nitrogen and C:N (r= -0.94, p<0.001, n = 40); Total nitrogen and CO_2 (r= -0.73, p<0.001, n = 40) and CO_2 and pH (r= -0.56, p<0.001, n = 40). For rice husk compost, total nitrogen was significantly and positively correlated with pH (r= 0.656, p<0.001, n = 40) but negatively correlated with C:N (r= -0.880, p<0.001, n = 40) and CO_2 (r= -0.642, p<0.001, n = 40). The CO_2 was negatively correlated with pH (r= -0.710, p<0.001, n = 40) (Appendix 2).

4.2.2 Evaluation of Compost and Compost-Biochar Mixes As Media for Lettuce and Ornamental African Marigold Production

4.2.2.1 Plant height of lettuce

At 2 WAT and 4WAT, there were no significant differences between the compost treatments with respect to plant height. However, at 6 WAT, 2-4MS3T (25.87 cm) 2-4RH3T (25.13 cm) produced significantly tallest plants, than 2-4SS3T (19.80 cm), 22MS3T (17.83 cm) and the control (19.50 cm) which produced the shortest plants (Table 4.7).

Table 4.7: Plant height of lettuce as influenced by the mature compost

Compost type	Plant height (cm)		
	2WAT	**4WAT**	**6WAT**
2-2SS3T	8.37	16.00	22.63
2-3SS3T	11.40	17.63	23.20
2-4SS3T	11.77	16.27	19.80
2-2MS3T	9.67	13.60	17.83
2-3MS3T	8.87	15.33	20.07
2-4MS3T	13.30	18.97	25.87
2-2RH3T	10.63	17.10	23.60
2-3RH3T	9.23	13.90	23.23
2-4RH3T	9.30	16.53	25.13
CONTROL	11.00	14.30	19.50
p-value	0.051	0.169	0.027
LSD (0.05)	2.920	3.943	4.623

4.2.2.2 Leaf chlorophyll content and yield of lettuce

Plants treated with 2-4MS3T compost recorded significantly greatest leaf chlorophyll content (38.77 %) compared to the leaf chlorophyll content of plants treated with 22SS3T, 2-2RH3T and the control which recorded the least (Table 4.8). In relation to the control, there were no significant differences (p=0.717) in leaf fresh weight of lettuce among the treatment (Table 4.8).

Table 4.8: Chlorophyll Content and leaf yield of lettuce as influenced by the final compost

Compost	SPAD (%)	Fresh leaf weight (g)
2-2SS3T	26.23	21.40
2-3SS3T	36.90	28.30
2-4SS3T	36.53	28.30
2-2MS3T	33.87	22.00
2-3MS3T	32.63	25.70
2-4MS3T	38.77	36.90
2-2RH3T	27.40	25.00
2-3RH3T	31.47	22.70
2-4RH3T	29.13	23.10
CONTROL	30.67	21.60
p-value	0.019	0.717
LSD (0.05)	7.017	17.19

4.2.2.3 Performance of african marigold

4.2.2.3.1 Plant height

At 2 WAT, 2-2SS3TB produced significantly ($p<0.001$) the tallest plants, whereas 22MS3T produced the shortest plants which was similar to those produced by 2-2SS3T (Table 4.9). At 4 WAT, the trend was similar to that of 2 WAT. AT 6 WAT however, 22SS3T3B produced significantly the tallest ($p<0.002$) plants, while 2-2MS3T produced the shortest plants which was similar to those produced by 2-2MS3T4B (Table 4.9).

Table 4.9: Plant height of marigold in different compost-biochar mixes

	Plant height (cm)		
Compost-biochar mix	**2 WAT**	**4 WAT**	**6 WAT**
2-2SS3TB	20.00	32.25	49.30
2-2SS3T2B	18.30	29.65	48.13
2-2SS3T3B	18.15	29.53	56.20
2-2SS3T4B	18.65	29.50	51.58
2-2SS3T	16.50	28.23	46.35
2-2MS3TB	19.38	30.18	51.13
2-2MS3T2B	17.73	28.45	50.78
2-2MS3T3B	18.78	28.98	51.80
2-2MS3T4B	18.90	28.18	44.03
2-2MS3T	15.95	24.38	38.58
p-value	0.153	0.042	0.004
LSD (0.05)	2.806	3.784	7.401

4.2.2.3.2 Number of leaves of marigold

At 2 WAT, 2-2SS3TB resulted in the production of the greatest number of leaves, significantly higher than 2-2MS3T which resulted in the least production of leaves but similar to those produced by 2-2SS3T (Table 4.10). At 4 WAT, 2-2MS3T3B produced the highest number of leaves whiles 2-2MS3T4B produced the least. AT 6 WAT however, 2-2MS3T3B produced significantly the highest number of leaves ($p<0.002$) plants whiles 2-2SS3T produced the least number of leaves which was not different from to those produced by 2-2MS3T4B (Table 4.10).

Table 4.10: Number of marigold leaves in different compost-biochar mixes

	Leaf number		
Compost-biochar mix	**2 WAT**	**4 WAT**	**6 WAT**
2-2SS3TB	12.00	23.25	39.25
2-2SS3T2B	10.50	24.00	39.75
2-2SS3T3B	11.00	24.00	40.25
2-2SS3T4B	12.50	22.50	37.75
2-2SS3T	9.75	21.00	34.25
2-2MS3TB	10.50	23.75	39.25
2-2MS3T2B	11.00	24.50	39.50
2-2MS3T3B	11.25	26.00	44.25
2-2MS3T4B	10.50	20.50	35.50
2-2MS3T	8.75	23.25	38.25
p-value	0.005	0.695	0.783
LSD (0.05)	1.647	5.587	10.16

4.2.2.3.3 Number of flowers of marigold

2-2SS3T3B compost resulted in production of greatest number of flowers (16) significantly greater ($p<0.004$) than 2-2SS3TB, 2-2MS3T2B, 2-2MS3T4B, 2-2SS3T, 22MS3TB and 2-2MS3T3B and 2-2MS3T, but similar to those produced by 2-2SS3T2B, 2-2SS3T4B, 2-2SS3T, 2-2MS3TB and 2-2MS3T3B. The 2-2MS3T had the least number of flowers similar to those produced by 2-2SS3TB, 2-2MS3T2B, 2-2MS3T4B, 2-2SS3T, 2-2MS3TB and 2-2MS3T3B (Figure 4.6).

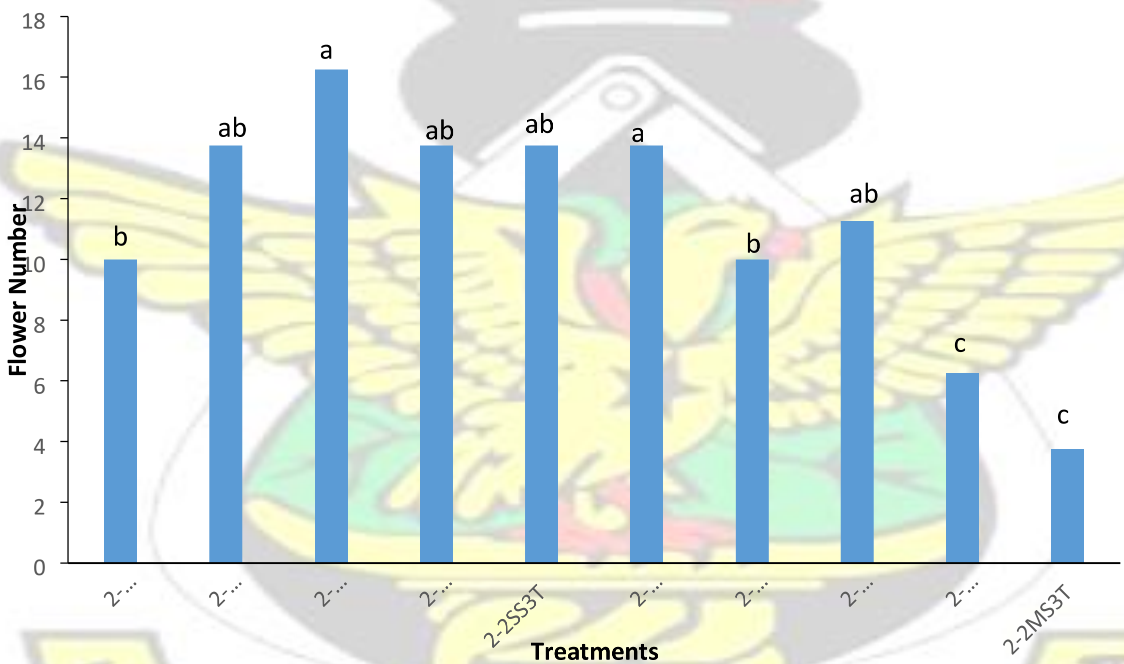

Figure 4. 9: Flower number of Marigold in different compost-biochar mixes

4.2.3 Evaluation of the Response of Lettuce and Ornamental Zinnia to Different

Ratios of Compost as Amendment

4.2.3.1 Media moisture and temperature profiles in compost amended soils

The 1-2MST compost had significantly highest (p=<0.001) media moisture of 61.30 %, 50.7 % and 62 .5 % volumetric water content (vwc) at 1, 2 and 3 WAT, respectively (Table 4.11). The control had the lowest vwc of 13.03 %, 13.57 and 13.87 at 1, 2 and 3 WAT, respectively. The control also had the highest media temperature of 33.9 ˚C (P=0.043), and 33.77 ˚C (p=0.017) 1 and 3 WAT respectively (Table 4.11).

Table 4.11: Effect of compost and soil-compost mixes on media moisture and temperature

Compost	Moisture (%)			Temperature (^{O}C)		
	1 WAT	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT
1-2SST	50.17	28.00	52.80	30.70	33.10	33.53
1-2SS2T	29.77	19.60	26.50	31.20	33.10	33.36
1-2SS3T	20.73	26.30	26.20	30.50	33.50	33.63
1-2MST	61.30	50.70	62.50	31.60	33.43	33.70
1-2MS2T	49.93	36.20	48.90	31.33	33.23	33.20
1-2MS3T	27.80	24.90	37.50	30.77	33.33	33.30
1-2RHT	51.63	28.10	32.80	31.13	33.36	32.93
1-2RH2T	26.50	18.50	18.40	31.17	33.40	33.36
1-2RH3T	16.50	13.80	15.00	31.00	33.50	33.33
Control	13.03	13.57	13.87	33.90	34.63	33.77
p-value	<.001	0.041	<.001	0.043	0.077	0.017
LSD (0.05)	4.506	20.60	18.83	1.779	0.8821	0.4167

4.2.3.2 Growth and leaf yield of lettuce

The 1-2RH3T produced significantly the tallest plants of 16.3 cm (p=0.030,) which was similar to those produced by 1-2SS3T, 1-2MST and the Control (Table 4.12). The 12MS2T and 1-2RHT produced the shortest plants. The 1-2RH3T had significantly more leaf numbers of 7; (P=0.001) which was similar to those produced by 1-2SS3T. The control had the least leaf number of 2.6 (p=0.001). The 1-2RH3T produced significantly the greatest fresh leaf weight of 6.3 g, the greatest fresh biomass of 6.86 g and the highest dry biomass of 0.570 g. The 1-2RHT produced the lowest leaf, fresh and dry biomass weights. (Table 4.12).

Table 4.12: The effect of soil-compost ratio on lettuce growth and yield parameters

Compost	Plant height (cm)	Fresh leaf		Biomass weight (g)	
		Leaf number	Weight (g)	Fresh	Dry
1-2SST	10.10	5.33	1.76	2.02	0.20
1-2SS2T	11.00	5.33	1.86	2.18	0.22
1-2SS3T	13.00	6.00	3.53	3.90	0.34
1-2MST	12.60	5.67	2.60	2.89	0.23
1-2MS2T	9.20	3.67	1.00	1.27	0.14
1-2MS3T	11.40	5.00	2.15	2.50	0.22
1-2RHT	9.20	4.33	0.90	1.13	0.12
1-2RH2T	11.70	5.67	2.39	2.83	0.28
1-2RH3T	16.30	7.33	6.34	6.86	0.57
Control	12.90	2.67	1.71	2.08	0.21
p-value	0.030	0.001	0.010	0.008	0.005
LSD (0.05)	3.788	1.644	2.464	2.534	0.1841

4.2.3.3 Growth and biomass of zinnia

The 1-2MS3T produced significantly (p=0.003) the tallest zinnia plants of 34.9 cm (p=0.003), similar to those produced by 1-2SST, 1-2SS2T, 1-2SS3T, 1-2MS2T, 1-2RHT and 1-2RH3T. The Control produced the shortest plants of 23.1, which were similar to those produced by 1-2MST and 1-2RH2T. The 1-2SST and 1-2MS2T gave the highest SPAD values (36.47 % each) (p=0.046) which were similar to the SPAD value of other compost amended treatments. The control produced significantly the lowest SPAD value of 31%. The 1-2RHT produced the highest fresh zinnia biomass of 15 g (p<0.00), similar to those produced by 1-2SST, 1-2MS2T, 1-2MS3T and 1-2RH3T. The control had the lowest fresh biomass of 1.65 g. The 1-2MS3T produced the highest dry biomass of 6.12 g, (p=<0.001) similar to those produced by 1-2SS2T, 1-2SS3T, 1-2MS2T. 1-2RH2T and 1-2RH3T. The control had significantly the lowest dry biomass of 0.8 g. (Table 4.13 and Plate 1).

Table 4.13: Effect of soil-compost mixes on zinnia growth and biomass

Compost type	Plant height (cm)	SPAD (%)	Fresh biomass (g)	Dry biomass (g)
1-2SST	31.05	36.47	12.07	2.42
1-2SS2T	34.50	34.87	8.99	5.30
1-2SS3T	32.52	34.02	7.32	5.15
1-2MST	27.22	31.77	8.64	3.20
1-2MS2T	32.30	36.47	11.86	5.62
1-2MS3T	34.95	35.80	13.67	6.12
1-2RHT	34.60	35.68	15.00	4.08

1-2RH2T	28.40	33.97	10.57	5.35
1-2RH3T	34.70	36.05	13.11	4.58
Control	**23.12**	**31.00**	**1.65**	**0.80**
p-value	0.003	0.046	<0.001	<0.001
LSD (0.05)	5.765	3.693	4.441	1.7

4.2.3.4 Flower development in zinnia

There were no significant differences in flower number among the treatments. The 12RH2T however, produced significantly the greatest flower head diameter of 2.27 cm, (p=0.008) similar to those produced by the other compost amended treatment, except 12SS3T and the control which had significantly lower flower diameters of 1.07 and 0.3 cm, respectively (Table 4.13). The 1-2MS2T produced significantly greatest flower head weight of 3.06 g, p=0.002, similar to those produced by 1-2MS3T and 1-2RH2T. The control produced the lowest flower head weight of 0.41 g. The 1-2SS2T produced the longest flower stalk length of 9.40 cm (p<0.001), similar to those produced by 1-2SS3T, 1-2MS2T, 1-2MS3T, 1-2RH2T and 1-2RH3T. The control had the lowest flower stalk length of 0.5 cm (Table 4.14).

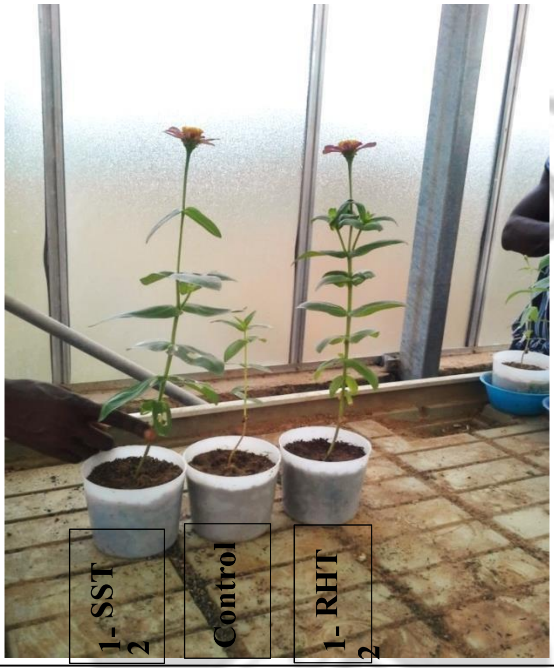

Plate 1. 1-2SST and 1-2RHT produced taller plants and fully developed flowers than control at 6

Table 4.14: Effect of soil-compost mixes on zinnia flower development

Compost	Flower No.	Head Diameter (cm)	Head weight (g)	Stalk length (cm)
1-2SST	2.25	1.99	1.89	3.83

1-2SS2T	1.50	1.38	1.75	9.40
1-2SS3T	1.25	1.07	1.55	8.28
1-2MST	2.50	1.76	1.56	5.25
1-2MS2T	2.50	1.86	3.06	6.30
1-2MS3T	2.75	2.06	2.68	7.85
1-2RHT	3.75	2.20	1.88	5.45
1-2RH2T	2.50	2.27	2.33	7.35
1-2RH3T	2.75	2.08	1.80	8.85
Control	**1.00**	**0.30**	**0.41**	**0.50**
p-value	0.883	0.008	0.002	<0.001
LSD (0.05)	2.223	0.989	1.017	3.485

4.2.4 Evaluation of the Response of Lettuce and Ornamental Zinnia to Soilless Media and Irrigation

4.2.4.1 Moisture regime in compost-biochar soilless media

The interaction effect of media and irrigation was not significant, but the main effect of media was significant. The sawdust compost soilless treatments retained significantly ($p<0.001$) more moisture than the rice husk compost soilless treatment from 1 up to 21 days after transplanting (Figure 4.10).

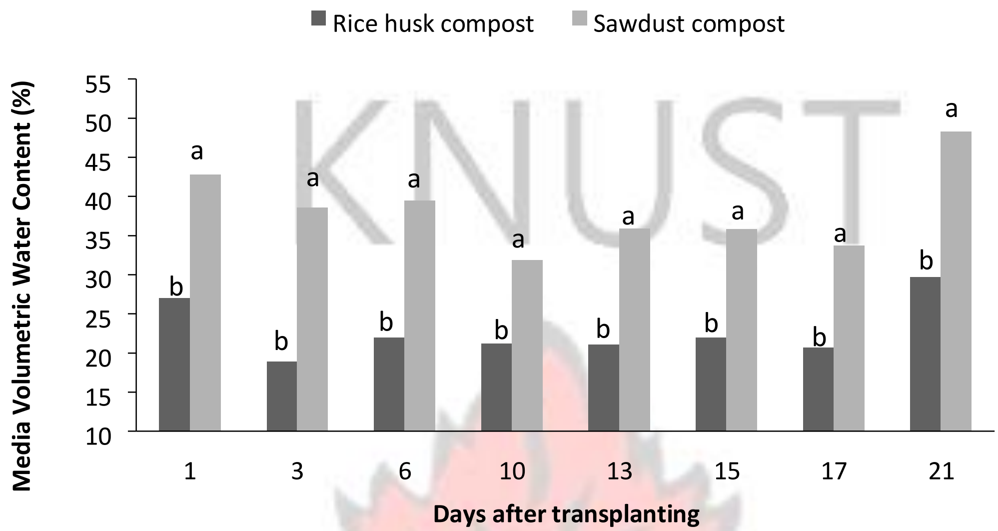

Figure 4.10: The effect compost type on media moisture content

4.2.4.2 Growth and yield response of lettuce

There were significant intereaction of soilless media by irrigation on the growth and yield of lettuce. The 2SS x 0.1125mm irrigation level interaction produced significantly (P<0.001) the tallest plants (15.2 cm), although similar only to 1-2SS2RB x 0.225 mm Irrigation level. The 1-2SS2RB x 0.1125 mm irrigation produced the shortest plants, similar to those produced by 2RH x 0.1125 mm Irrigation level, 1-2SSRB x 0.225 mm, 12RH2RB x 0.225 mm, 2SS x 0.255 mm and 1-2SSRB x 0.1125 mm (Table 4.15). The 1-2SS2RB x 0.225 mm Irrigation level produced significantly (p<0.001) more leaf numbers (7.2) similar to that produced by 1-2RH2RB x 0.225 mm. The 2RH x 0.1125 mm, 2RH x 0.225 mm irrigation interaction and 1-2SSRB x Irrigation II interaction produced the lowest leaf numbers (Table 4.15).

The 1-2SS2RB x 0.1125 mm interaction produced significantly ($p<0.001$) highest SPAD value (28.6 %) similar to those produced by other soilless media plus irrigation interactions except 1-2RHRB x 0.1125 interaction and 1-2RH2RB x 0.225 mm interaction which had the lowest SPAD values of 24.0 % and 23.4 % respectively (Table 4.15).

The 1-2SS2RB x 0.255 Irrigation produced significantly greatest leaf weight (6.16 g) similar to those produced by 1-2RH2RB x 0.225 irrigation interaction and 2SS x 0.1125 irrigation interaction. All the other treatments had similar fresh leaf weights (Table 4.15).

Table 4.15: Effect of compost-biochar soilless media and irrigation on lettuce Growth and yield

	Plant height (cm)		Leaf number		SPAD (%)		Leaf weight (g)	
Compost	0.1125mm	0.225mm	0.1125mm	0.225mm	0.1125mm	0.225mm	0.1125mm	0.225mm
2RH	9.1	0.0	4.0	0.0	28.3	0.0	1.34	0.00
1-2RHRB	11.1	9.1	5.5	4.5	24.0	25.9	2.06	1.38
1-2RH2RB	10.4	12.2	4.5	6.5	24.9	23.4	1.76	4.36
2SS	15.2	10.0	5.0	6.0	24.3	26.3	4.6	3.58
1-2SSRB	9.5	9.9	4.7	4.0	26.8	27.5	0.93	1.30
1-2SS2RB	8.0	14.7	5.0	7.2	28.6	26.8	1.77	6.16
LSD (0.05)								
Compost	2.049		0.5213		3.091		1.310	
Irrigation	1.183		0.3010		1.784		0.756	
Compost x irrigation	2.898		0.7373		4.371		1.853	

4.2.4.3 Growth and flower quality response of *zinnia elegans*

The interaction effect of media and irrigation was not significant for growth and yield parameters of zinnia. The main effect of irrigation was not also significant and hence the main effect of media is presented here for relevant parameters. The 1-2RHRB2 media produced significantly ($p=0.013$) tallest (39.2 cm) zinnia plants, similar to those produced by 1-2SSRB and 1-2SS2RB. The 2RH media produced the shortest zinnia plants of 23 cm (Table 4.16). The 2SS and 1-2SS2RB produced significantly highest flower number of 4 each ($p<0.001$), similar to that produced by 1-2SSRB (Table 4.16). The 1-2RHRB produced the least number of flowers of 1.7. The 1-2RH2RB produced significantly ($p=0.020$) the highest flower head diameter of 4 cm, similar to those produced by 2RH, 2SS and 1-2SSRB (Table 4.16). The 1-2SS2RB had the least flower head diameter of 1.5 cm.

Fresh biomass was significantly highest (14.6 g; $p<0.001$) in 2SS media, similar to those produced by 1-2SSRB and 1-2SS2RB. Fresh biomass was lowest in 1-2RH2RB. Dry biomass was significantly highest ($p<0.001$) in 1-2SS2RB, although similar to that produced by 2SS. The 2RH had the least dry biomass. The 1-2RH2RB produced the longest flower stalk length of 5 cm, ($p=0.038$), similar to that produced by 1-2SSRB. The 1-2RHRB had the shortest stalk length (Table 4.16).

Table 4.16: Effect of compost-biochar ratio on zinnia growth & flower quality

Compost–biochar	Plant height (cm)	No. flowers	Head diameter (cm)	Fresh biomass (g)	Dry biomass (g)	Stalk length (cm)
2RH	23.00	2.10	2.51	5.38	0.83	3.01
1-2RHRB	29.20	1.80	2.10	7.28	0.93	2.81
1-2RH2RB	39.20	1.70	4.00	4.02	1.22	5.96
2SS	29.00	4.00	2.38	14.65	1.98	3.12
1-2SSRB	35.90	3.00	3.99	11.32	1.50	4.41
1-2SS2RB	32.60	4.00	1.51	10.61	2.15	2.82
p-value	0.013	<0.001	0.02	<0.001	<0.001	0.038
LSD (0.05)	8.86	1.109	1.65	4.302	0.5066	2.218

4.2.5 Field Study: Evaluation of Compost-Biochar Mixes in the Production of *Amaranthus*

4.2.5.1 Growth response of *Amaranthus*

The 2SS compost plus single species sawdust biochar (2SS+SSB) produced significantly the biggest (p=0.029 stem girth of 14.86 cm, although it was similar to the stem girth produced by 2RH plus rice husk biochar (2RH+RHB), 2RH+SSB) 2RH and 2SS compost. The control treatment produced the smallest stem girth. The 2SS+SSB produced significantly more leaves (30.3) than all the other treatments. The Control had the least number of leaves (15). The 2RH+RHB had significantly the highest SPAD value of 42.1 % than all the other treatments. The control had the least SPAD value of 17.9 %

(Table 4.17).

Table 4.17: Effect of amendments on growth parameters of *amaranthus*

Amendment	Stem girth (mm)	Leaf No.	SPAD (%)
2SS+SSB	14.86	30.33	29.37
2SS+RHB	10.80	21.30	21.17
2RH+-RHB	11.87	19.23	42.10
2RH+SSB	12.04	20.00	28.07
2RH	11.48	19.33	29.37
2SS	12.80	20.33	33.27
CONTROL	7.43	15.33	17.93
p-value	0.02	<.001	<.001
LSD (0.05)	3.38	4.18	6.82

4.2.5.2 Yield response of A*maranthus*

2SS+SSB produced significantly the highest fresh biomass of 98.3 g (p=0.003) compared to all other treatments. The control had the least fresh biomass of 23.5 g. The 2SS+SSB had the highest dry biomass of 22.3 g (p=0.050), similar to the other amended treatments. The control treatment produced the least dry biomass of 5.6 g. The 2SS+SSB had the highest dry root weight of 9.58 (p=0.001), only similar to that produced by 2SS+RHB. The Control also had the least dry root of 2.7 g. The 2SS+SSB mixes were more efficient in water use (130 kg m^{-3}) whereas the control had the least water use efficiency of 3 kg m^{-3} (Table 4.18).

Table 4.18: Effect of amendments on yield parameters of *amaranthus* growth

Amendment	Fresh biomass (g)	Dry biomass (g)	Dry root (g)	Water use (kg m^{-3})
2SS+SSB	98.3	22.3	9.5	130.0
2SS+RHB	64.5	14.6	6.5	90.0
2RH+RHB	54.4	10.6	5.3	60.0
2RH+SSB	56.0	11.4	4.9	70.0
2RH	46.5	10.1	3.9	20.0
2SS	59.0	16.9	6.1	10.0
Control	23.5	5.60	2.7	3.0
p-value	0.003	0.050	0.001	0.59
LSD (0.05)	26.80	9.80	3.05	0.185

4.2.6 Evaluation of Compost-Biochar as Soilless Media for Greenhouse Production of Sweet Pepper and Runner Beans

4.2.6.1 Plant height of sweet pepper

Plant height of sweet pepper was significantly influenced by the treatments applied. Between 3 and 7 WAT, the Coir treatment (Control) produced significantly the tallest plants compared to the other soilless media ($p<0.001$). However at 8 WAT, the sawdust compost + rice husk biochar (2SS+RHB) was the only organic soilless substrate that produced similar plant height as the Coir ($p<0.001$). At 10 WAT, the 2SS+RHB and

2SS+SSB produced significantly (p<0.001) the tallest plant height of 70.3 and 70.3 cm, respectively as compared to the Coir (65.5 cm) (Figure 4.11).

At full maturity, plant height and plant physical development (based on pictorial observation) were influenced by treatment in the order, 2SSS+RHB > 2SS+SSB > Coir > 2RH+RHB > 2RH+SSB **(**Plate 2).

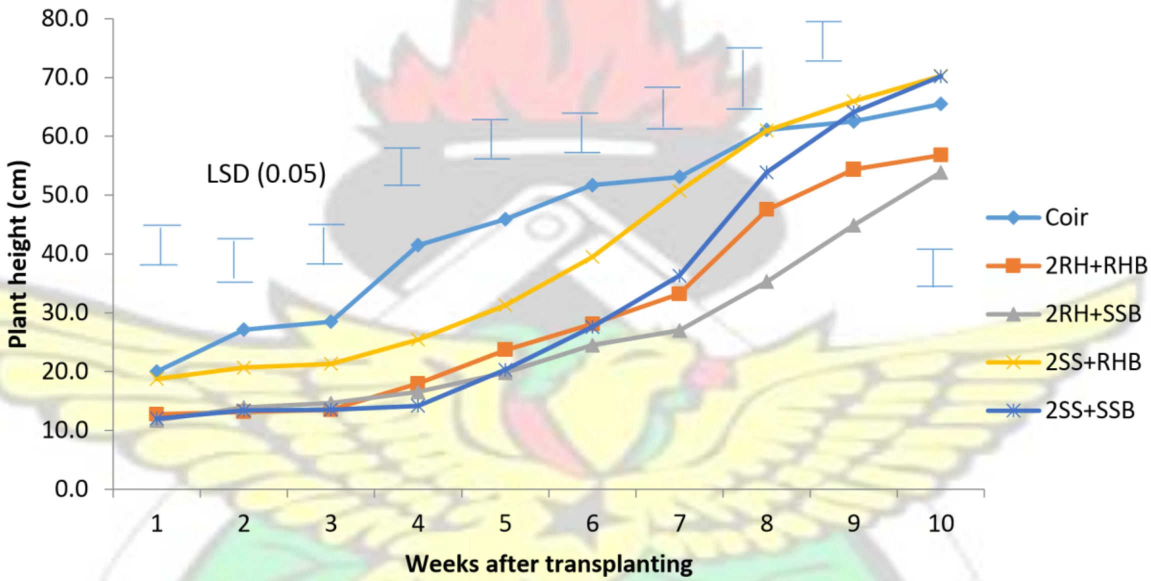

Figure 4.11: Effect of soilless substrate on plant height of sweet pepper (bars=LSD at 0.05)

Plate 2: Comparing the development response of sweet pepper to the soilless media

4.2.6.2 Leaf number of sweet pepper

Similar results were obtained for leaf number, where the Coir had significantly highest leaf number between 3-7 WAT ($p<0.001$). However, at 10 WAT, the 2SS+2SSB produced significantly ($p<0.003$) more leaf number of 81 similar to 2SS+2RH and the Coir, but higher than all other treatments (Table 4.19).

Table 4.19: Effect of soilless substrate on leaf number of sweet pepper

	Leaf number								
Media	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Coir	28.5	41.0	55.7	61.0	63.0	68.2	70.2	73.5	75.8
2RH+RHB	9.5	10.0	16.0	24.8	31.0	40.0	63.0	67.8	71.0
2RH+SSB	9.0	9.0	14	21.2	23.8	30.5	42.5	47.8	62.2
2SS+RHB	13.7	14.7	21.2	33.2	38.8	62.0	71.5	76.8	79.2
2SS+SSB	9.7	9.0	12.0	21.0	30.0	43.0	68.8	77.5	81.8
p-value	<.001	<.001	<.001	<.001	<.001	<.001	0.001	<.001	0.003
Lsd (0.05)	3.724	4.071	4.813	9.49	8.43	9.67	11.99	8.14	8.75

4.2.6.3 Plant girth of sweet pepper

In the case of plant girth, the Coir treatment again produced significantly ($p<0.001$) the highest plant girth between 3-7 WAT. However, at 10 WAT; the 2SS+RHB produced significantly highest stem girth ($p<0.002$) similar to the Coir, but higher than all the other treatments (Figure 4.9).

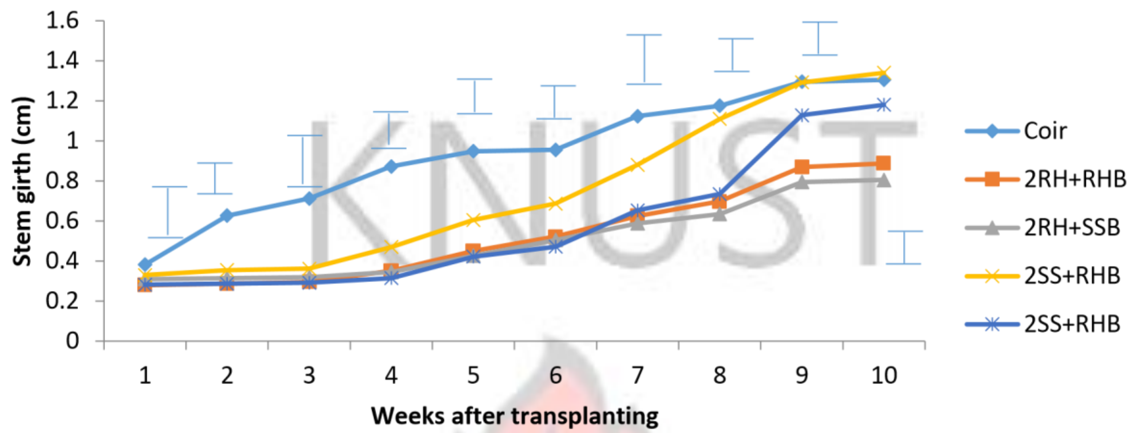

Figure 4.12: Effect of soilless substrate on stem girth of sweet pepper (bars=LSD at 0.05)

4.2.6.4 Flower bud numbers and number of flowers of sweet pepper

No significant differences were observed in flower bud numbers at 5, 6 and 8 WAT. However, at 7 WAT, the Coir treatment produced significantly highest bud numbers of 6.2,5 similar to that produced by 2RH+RHB. 2SS+RHB had the least number of flower buds at 7 WAT (Table 4.20).

Table 4.20: Effect of soilless media treatments on flower bud number of sweet pepper

	Flower bud Number			
Treatment	**5 WAT**	**6 WAT**	**7 WAT**	**8 WAT**
2RH+RHB	3.75	4.25	4.50	1.25
2RH+SSB	2.00	3.25	2.00	2.75
2SS+RHB	4.75	3.00	1.50	1.75
2SS+SSB	2.00	2.00	2.75	2.00
Coir	4.75	3.25	6.25	5.25
p-value	0.352	0.784	0.046	0.11
Lsd (0.05)	3.859	3.766	3.289	3.151

At 5 WAT, the Coir produced significantly (p=0.010) highest number of flowers of 6.25, similar to that of 2RH+RHB. All the other treatments had significantly lower flower numbers. There were no significant differences in flower numbers at 6, 7 and 8 WAT (Table 4.21).

Table 4.21: Effect of soilless media treatments on flower number of sweet pepper

	Flower number			
Treatment	**5 WAT**	**6 WAT**	**7 WAT**	**8 WAT**
2RH+RHB	5.00	2.50	1.25	2.25
2RH+SSB	0.75	3.00	1.75	2.00
2SS+RHB	0.00	4.00	2.00	1.50
2SS+SSB	2.00	2.00	2.75	2.75
Coir	6.25	2.00	0.50	4.00
p-value	0.01	0.95	0.72	0.83
Lsd (0.05)	3.588	6.402	3.555	4.878

4.2.6.5 Fruit number, fruit weight and fresh biomass of sweet pepper

The SDC-RHB gave significantly ($p<0.001$) the highest fruit number (5) and the highest fresh biomass (243 g) per plant at harvest ($p<0.001$), while the 2RH+SSB gave the lowest fruit number (0.75) and the lowest fresh biomass (47.5 g) per plant. The 2SS+SSB however, produced significantly (p=0.002) the highest fruit weight (102 g) per plant, whilst 2RH+SSB gave the least fruit weight (15.5 g) per plant (Table 4.22).

Table 4.22: Effect of soilless media on fruit no. fruit weight and biomass of sweet pepper

Treatment	Fruit No	Fruit Weight (g)	Fresh biomass (g)
2RH+RHB	1.75	58.00	65.00
2RH+SSB	0.75	15.50	47.50
2SS+RHB	5.25	96.50	243.00
2SS+SSB	4.75	102.00	208.50
Coir p-value	3.25	50.50	196.50
	<.001	0.002	<.001
Lsd (0.05)	1.616	37.22	45.84

4.2.6.6 Plant height of runner beans

Although the Coir produced significantly greatest plant height than all other treatments at 3 and 5 WAT (p=0.008 and p=0.034), there were no significant differences in plant height at 6 WAT (Table 4.23).

Table 4.23: Plant height of runner beans as affected by different soilless media

	Plant height (cm)					
Treatment	**1 WAT**	**2 WAT**	**3 WAT**	**4 WAT**	**5 WAT**	**6 WAT**
2RH+RHB	17.3	19.4	21.5	17.6	17.5	11.6
2RH+SSB	15.7	15.9	16.0	12.7	7.7	7.7
2SS+RHB	20.8	21.1	21.2	21.4	21.5	16.4
2SS+SSB	15.3	15.4	15.4	12.8	10.4	10.5
Coir	22.2	22.4	22.9	23.0	23.3	18.4
Fpr	0.287	0.088	0.008	0.126	0.034	0.416
Lsd	7.98	5.92	4.417	9.85	10.88	13.1

4.2.6.7 Leaf number per plant of runner beans

For all the weeks data was taken, leave development was consistently and significantly higher in the Coir treatment than the other treatments. The coir produced significantly highest leaf number of 29 at 6 WAT whereas the 2RH+SSB produced the least number of leaves of 5 (Table 4.24).

Table 4.24: Leaf number of runner beans as affected by different soilless media

	Leaf number					
Treatment	**1 WAT**	**2 WAT**	**3 WAT**	**4 WAT**	**5 WAT**	**6 WAT**
2RH+RHB	6.0	7.7	21.5	10.0	8.2	7.0
2RH+SSB	7.0	9.5	16.0	6.0	5.0	5.2
2SS+RHB	6.0	7.5	21.2	9.0	10.2	8.8
2SS+SSB	6.0	8.7	15.4	7.0	9.0	11.5
Coir	10.0	17.2	22.9	34.0	32.2	29.2
p-value	0.011	<.001	0.008	<.001	<.001	0.006
Lsd (0.05)	2.337	3.198	4.417	7.23	9.09	12.13

4.2.6.8 Stem girth per plant of runner beans

Between 2-4 WAT, stem girths (0.52 cm to 0.58 cm) were highest in the Coir treatment than other treatment. However, at 5 and 6 WAT, the stem girth of 2SS+RHB (0.43 cm) was similar to the Coir which had stem girth of 0.67 cm (Table 4.25).

Table 4.25: Stem girth of runner beans as affected by different soilless media

Treatment	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
			Stem girth			
2RH+RHB	0.435	0.44	0.435	0.43	0.32	0.22
2RH+SSB	0.415	0.44	0.44	0.35	0.24	0.13
2SS+RHB	0.393	0.39	0.39	0.39	0.41	0.43
2SS+SSB	0.45	0.47	0.46	0.33	0.22	0.22
Coir	0.523	0.53	0.54	0.58	0.63	0.67
p-value	0.016	0.007	0.006	0.233	0.02	0.004
Lsd (0.05)	0.0702	0.06135	0.0672	0.2404	0.2449	0.2543

4.2.6.9 Fruit number and weight of runner beans

There were no significant differences in fruit numbers and fruit weight among the treatments (Table 4.26). The 2RH+RHB and Coir produced no fruits

Table 4.26: Fruit number and fruit weight of runner beans as affected by soilless media

Treatment	Fruit No.	Fruit weight (g)
RHC-RHB	0.0	0.0
RHC-SDB	1.2	1.0
SDC-RHB	5.5	3.0
SDC-SDB	9.0	5.0
Coir	0.0	0.0
p-value	0.092	0.077
Lsd (0.05)	7.64	4.018

4.2.7 Evaluation of Cost of Producing a Unit Weight of Compost

In Kumasi, it cost 0.36 and 0.41 Cedis to produce a kg of rice husk compost and sawdust compost respectively. In Tamale the cost of producing a kg of rice husk compost and sawdust compost is 0.35 and 0.50 Cedis, respectively (Table 4.27).

Table 4.27: Cost of production of sawdust and rice husk compost in Tamale and Kumasi

Cost item	Kumasi		Tamale	
	Rice Husk (GHS) (GHS)	Sawdust (GHS)	Rice Husk	Sawdust (GHS)
1 m^3 Boxes (depreciation)	13.5	13.5	18.7	18.7
Lining of boxes	5.0	5.0	4.0	4.0
Mixing of materials	20.0	20.0	16.0	16.0
84 kg of poultry manure (cost)	30.0	30.0	15.0	15.0
100 kg of sawdust (transport)	0.0	30.0	0.0	60.0
113 kg of rice husk (transport)	30.0	0.0	25.0	0.0
Water (per ECG bill)	2.3	2.3	2.3	2.3
Water cans (depreciation)	2.0	2.0	4.0	4.0
Large basin(depreciation)	0.0	0.7	0.0	1.5
Thumb nails	6.3	6.3	12.6	12.6
Polythene sheet (8 yards)	25.0	25.0	32.5	32.5
Harvesting (labour 1 man day)	10.0	10.0	8.0	8.0

Total/ 3 replicates	**144.1**	**144.9**	**138.18**	**174.76**
Amount/box	48.04	48.30	46.06	58.25
Kg of compost/box	131.3	116.6	131.3	116.6
Amount/kg	**0.36**	**0.41**	**0.35**	**0.50**

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 CURRENT TYPES OF ORGANIC AMENDMENTS AVAILABLE AND THEIR USES IN TAMALE AND KUMASI

The urban landscape prominently featured urban horticultural practitioners who were involved in vegetable and ornamental plants production. These practitioners are mostly educated especially in Kumasi and are aware of soil amendments derived from organic residues. Practitioners were generally within the active age range of 20-40 years and this could have influenced awareness and use. Supaporn *et al.* (2013); Drechsel and Keraita, (2014) indicated that factors such as age and education outreach programmes influenced farmer awareness and adoption of organic amendments.

Farmer adoption of amendments also depended on spatial and temporal availability of organic materials at the local levels. Studies on resources availability in Tamale, suggested that organic materials such as rice husk and wood waste were available for composting (Duku *et al.,* 2011). Issaka *et al.,* (2012) reported that raw materials (feedstock) availability for processing into rich compost was not a limitation to adoption of organic amendments in Tamale and Kumasi. The wood industry was more developed in Kumasi and therefore sawdust had more potential application, whereas the developed rice industry in Tamale offered a good potential for rice husk application. Poultry manure was available in both cities, yet there was a high level of adoption of poultry manure in

Kumasi and cow manure in Tamale. This is not surprising because the poultry industry is more developed in Kumasi and the cattle industry is more prominent in Tamale. Collection of waste materials for composting is a major investment and sometimes requires technologies beyond the reach of small scale farmers. Some waste materials such as market waste and urban solid waste are not ideal for small scale composting. The cost involved in collecting municipal solid waste and the quality issues associated with solid waste composting serve as a serious disincentive for decentralised composting schemes. Farmers therefore find it cost effective to use materials within their vicinity where collection cost is less and where they are also assured of the quality of the waste material and the resulting compost. The findings support the conclusion of Bellwood-Howard (2013) that farmer's decision to compost is influenced by factors such as; the need to compost and the availability of potential compost raw materials.

The main challenges limiting the use of soil amendments were transport and labour for application of the amendment. A bicycle could easily carry 1 bag of inorganic fertilizer meant for an acre. However, to carry the equivalent number of compost for an acre (i.e 10-15) bags would require a truck, motor king (motor cycle with a trailer) or several trips with a bicycle. Most farmers have bicycles in Tamale. Only a few farmers can afford to buy a Motor king. Moreover, "Motor King" services are available to all farmers but at an extra cost. These findings are consistent with reports of compost use in West Africa (Lawal *et al.,* 2007). The transport challenges may partly explain why farmers use less (1.7 to 3.4 ton ha^{-1}) than the recommended rate of 10-20 ton ha^{-1} (Bellwood-Howard, 2013). Although the technology for composting is available, current paradigm for composting appears to be linked to waste recycling and solid waste management in urban areas (Olufunke *et al.*, 2006). This approach often leads to the compost developers paying less attention to the quality of compost especially for different uses in urban horticulture. Farmers are aware of the production and economic gains that can accrue from the use of organic amendments and they identified variable quality of amendments as a major weakness. These suggest that standardisation may increase adoption rates.

5.2. CHARACTERISATION AND FORMULATION OF FEEDSTOCK AND COMPOSTING

The physical and chemical compositions of the feedstock were within limits given for quality feedstock needed for composting (Leconte *et al.*, 2009). The characterisation indicated that the poultry manure used as N source was high in N and P and thus corroborates the findings of Leconte *et al.*, (2011) that poultry manure being high in N and P, always results in the formulation of high quality compost. In characterising feedstock for composting, the C:N ratios are critical as they determine the length of the thermophilic phases and also the maturity of the final compost.

The results showed higher temperatures and longer temperature peaks for the higher ratios (4:1 and 3:1) than the lower ratios (2:1). This result may be due to the fact that the higher ratios have more carbonaceous feedstock than the lower ratios. More carbonaceous material feedstock may need a greater microbial activity to generate enough temperature for carbon breakdown (Leconte *et al*., 2009)

The rice husk feedstock which was less carbonaceous gave the shortest thermophilic range. The nature of carbonaceous materials ultimately determines the length of the thermophilic phase. Higher temperatures are known to be associated with ammonia volatilization (Leconte *et al.,* 2009). The thermophilic temperatures of 45-70 ^{O}C are also reported to be critical in killing weed seeds and pathogens that may be in the feedstock (Gao *et al.,* 2010). The 2SS compost attained the highest temperature of 60 ^{O}C and mees the conditions specified by Gao *et al.,* (2010).

The results did not show variation in CO_2 due to the treatments. However, lower values were obtained at the start of composting and rising to significant level between 2-4 weeks, then dropping to the lowest as the compost matured. The CO_2 evolution is an indicator of microbial respiration and activities. Higher values indicate higher microbial activity. Higher respiration is known to increase compost temperature, although higher temperature could also result from thermic inertia (Tiquia *et al*., 2002). The levels of CO_2 were found to correlate positively with total nitrogen and negatively with pH. This suggested nitrification associated with increasing microbial activity.

The pH which depends partly on the nature of the initial feedstock has been reported as a good indicator of the progress of composting (Brewer and Sullivan, 2001). Generally, feedstocks of higher C:N value are known to generate high pH values during composting.

In the present study, the C:N value of rice husk was lower than sawdust and may account for the low pH of 3RH and 4RH even at 8-12 weeks of composting when all the other composts had pH values above neutral. This low pH (6.85) in the 3RH and 4RH composts could have been due to anaerobic conditions in the compost arising from the observed poor water absorption capacity of the composts which could have led to the accumulation of organic acids responsible for lowering pH in composts. The 2RH did, not however, suffer from low pH because of the addition of more poultry manure which caused a decrease in the C:N value due to the release of nitrogen (Leconte *et al*., 2011). In the present study, total nitrogen was found to correlate negatively with pH. All the compost produced in the present study were within the acceptable EC range of 0.75 and 2.35. EC which is a measure of soluble salts content of the compost. Higher EC is noted to cause severe phytotoxicity (Wilson *et al.,* 2001). Increase in EC could be due to the release of mineral salts that occur during the active phase of composting (GomezBrandon *et al*., 2008; Gao *et al*., 2010). Good salts result from the presence of K^+, Mg^{2+}, Ca^{2+}, NO_3^- and NH_4^+ whereas toxic salts results from the presence of Na^+ and Cl^-.

The soil used for soil-compost experiment is characteristics of soils in urban areas of the savannah ecological zone of Ghana. These soils are generally low in N, organic carbon and are slightly acidic (Abubakari *et al.*, 2011). As characteristics of these soils, P becomes very limited and soil analysis usually show trace levels of P (Abubakari, *et al*., 2012).

All the nine composts produced had qualities comparable to compost produced elsewhere using different feedstocks (Leconte *et al.*, 2009; Ali *et al.*, 2007; Jaysinghe *et al*., 2010). The compost produced from *Daniellia oliveri* sawdust recorded the highest N content of 2.46 % and exhibited maturity in the shortest time of 8 weeks. *Daniella Oliveri* is a leguminous tree and therefore the sawdust derived from it was less lignified compared to the other feedstock used. Combining *D. Oliveri* and *C. albidum* sawdust appeared to have increased the lignin content and increased the final C:N value of the resulting compost. Although the rice husk feedstock had the highest N and P levels, the mature rice husk compost had the lowest N and P values of 1.68 % and 45 mg/L respectively. The levels of NH_4-N in all the compost were within levels (<500 mg/kg) recommended for stabilised compost (Saeboa and Ferrini, 2006). The C:N ratio is an important measure of stability and hence maturity of compost (Gomez-Brandon *et al.,* 2008) and all the values found in the compost produced, except the 4RH, were within the levels acceptable for stabilised compost (15:1 – 25:1) as prescribed by the EU (Saeboa and Ferrini, 2006; Gomez-Brandon *et al.,* 2008). The implication for this is that there is a huge potential for the development of quality compost from locally available organic materials which can be used to increase crop production in Ghana. Upscaling of this work can support efforts to find alternative to high cost imported coir media and inorganic fertilizer.

In the present study, correlation analysis highlighted significant relationships among the compost maturity indices. In all the different feedstock used, TN was always positively correlated with pH, but negatively correlated with C:N and CO_2. This finding was significant as it indicated that as the degradation of carbon leads to the accumulation of nitrogen, pH reaches alkaline levels. This is associated with matured compost and CO_2 values decline because of reduced microbial activity associated with maturity.

Generally the total nitrogen was found to be significantly and negatively related to C:N ratio, an index of compost maturation. The extent of contribution of total nitrogen to the variation in the C:N ratio of the resulting compost, however, differed between the nature of the base raw material used. For single species sawdust compost, total nitrogen explained 92 % of the variation in the C:N content, whereas for the mixed species sawdust compost total nitrogen explained 87 % of the variation in the C/N content. Additionally, for the rice husk compost, total nitrogen explained 77 % of the variation in the C:N content.

The optimum C:N ratio for matured and stabilised compost is 12:1 to 15:1. A C:N ratio less than 10:1 indicates situations of incomplete composting associated with higher levels of N manures. C:N values of more than 25:1 indicate presence of raw carbonaceous materials which when applied to soil results in severe N drawdown (Saeboa and Ferrini, 2006; Evans *et al.*, 1996).

5.3 EVALUATION OF COMPOST AND COMPOST-BIOCHAR MIXES FOR LETTUCE AND ORNAMENTAL AFRICAN MARIGOLD PRODUCTION

The evaluation of the composts indicated that the 2 parts of 4MS compost plus 3 parts top soil (2-4MS3T) was more effective in promoting plant height and leaf chlorophyll content of lettuce. Application of this compost resulted in 32.7 % increase in plant height, 33.3 % increase in leaf chlorophyll compared to the control which is un-amended soil. However, effect of treatments on fresh leaf weight was not significant. The results indicated that, although the 2-4MS3T was lowest in N content, it had the lowest EC compared to all other compost. Probably, the lower EC could have been the reason for the enhanced performance of this compost on plant height and chlorophyll content as lettuce is reported to be sensitive to higher EC (Andriolo *et al*., 2005; Unlukara *et al*., 2008).

In the single species sawdust compost, the 2 parts 2SS + 3 parts topsoil + 3 parts biochar (2-2SS3T3B) resulted in 21.7 % increase in plant height and 60 % increase in flower numbers of marigold as compared to the 2 parts 2SS + 3 parts top soil without biochar. In the mixed species sawdust compost, 2 parts 2MS + 3 parts topsoil + 3 parts biochar (22MS3T3B) resulted in 34 % increase in plant height and 164 % increase in marigold flower numbers compared to 2 parts 2MS + 3 parts top soil without biochar. A combined media of compost and biochar improves nutrient and water retention (Liu *et al*., 2012). Nutrient use efficiency is believed to be the reason for enhanced biochar effect on growth and yield (Gaskin *et al*., 2010; Glaser *et al*., 2002; Lehmann *et al*., 2002).

5.4 EVALUATION OF THE RESPONSE OF LETTUCE AND ORNAMENTAL ZINNIA TO DIFFERENT RATIOS OF COMPOST AS AMENDMENT IN URBAN SOILS

In general, amending soils with compost increased the water retention characteristics of the media. Amending soils with 50 % compost (1:1) resulted in more than 100 % increase in water retention as compared with amending same soil with 25 % compost (3:1). The control treatment which had no compost amendment was at least three times lower in moisture retention compared to treatments amended with 50 % compost. This information is crucial for urban production systems that rely on marginal water resources. In many urban areas of the developing world, perennial sources of water are very limited and practitioners use marginal water resources including wastewater for vegetable and landscape plants. Where quality water is available such as tap water, it is often very expensive. According to Drechsel and Keraita (2014), a common complaint among urban farmers was that compost application increased the water demand of soil. This assertion could be explained by the fact that compost is hydrophilic until it gets to a saturation point, then it begins to act as a sponge, retaining water and preventing excessive losses to percolation. This observation of water demand was limited to the first few days after planting. These findings provide a great potential for the use of different volumetric ratios of compost as hydrophilic substances for moisture retention in the urban landscape. As climate change is projected to lead to declining nutrient and water resources, development of nutrient rich compost could become critical climate smart strategies for mitigation and adaptation (Fischer and Glaser 2012; Liu *et al*., 2012; Schulz and Glaser 2012).

The 1-part 2RH and 3 parts topsoil and 1 part of 2SS compost + 3 parts topsoil produced the best lettuce growth and yield. The 1 part 2MS + 2 parts topsoil and 1 part 2RH + 1 part topsoil were the worst in lettuce growth and yield. The results further indicated that increasing the ratio of compost to topsoil in the single species sawdust compost and rice husk compost led to increasing growth and yield of lettuce. This further supports earlier findings that lettuce is sensitive to EC and therefore diluting the compost by using higher ratios of compost reduces the EC and thus increasing the growth and yield of lettuce (Andriolo *et al*., 2005; Gomez-Brandon *et al.*, 2008; Unlukara *et al*., 2008; Gao *et al.*, 2010). The mixed species sawdust compost generally had very low EC and therefore the same results were not observed. Rather, lettuce growth and yield in the mixed species sawdust compost declined with increasing ratios of compost to sawdust.

In zinnia production, the 2 parts of 2MS + 3 parts topsoil (1-2MS3T) was the best for zinnia growth and the 2 parts 2MS + 1 part topsoil (1-2MST) was the worst for zinnia growth. In zinnia production however, the increasing ratios of single species and rice husk compost led to declining fresh and dry biomass, but did not lead to increasing or declining growth. In contrast, the increasing ratios of mixed sawdust compost led to increasing zinnia growth and biomass. Zinnia is known to be tolerant to higher levels of EC and this could explain why lower ratios of single species and rice husk compost with relatively higher levels of EC increased zinnia biomass (Carter and Grieve, 2010). With respect to zinnia as a cut flower, flower head diameter was highest in 1 part of 2RH compost

+ 2 parts topsoil (1-2RH2T), but no relationship was obvious between the ratios of 2RH compost and topsoil. In single species sawdust compost however, higher ratios were related to lower flower head diameter and lower flower head weight. In all three compost types used as amendment in the zinnia experiment (2SS, 2MS and 2RH), lower ratios of compost to soil resulted in shorter flower stalk length which is desirable as indicator of good cut flower quality. As the lower ratios of compost to soil are related to higher EC than the higher ratios, the lower ratios may be used as growth retardants to improve cut flower quality in place of synthetic growth retardants (Carter and Grieve, 2010). These findings suggest characterising and standardising organic materials enables identification of different compost types for different uses in both vegetable and ornamental plant production in the urban landscape.

5.5 EVALUATION OF THE RESPONSE OF LETTUCE AND ORNAMENTAL ZINNIA TO SOILLESS MEDIA AND IRRIGATION

In general, the sawdust soilless treatments performed significantly better than the rice husk soilless treatments in promoting better media moisture content, plant height, leaf number and yield. The 2SS x 0.1125 mm irrigation interaction was best for lettuce growth (plant height, leaf number) and yield (fresh leaf weight,). The 1 part 2SS + 2 parts rice husk biochar x 0.255 mm irrigation interaction was consistently best in promoting lettuce growth and yield. This finding could be influenced by the hydrophobic (acting as a desiccant and drains the media of excess water) nature of biochar which could have triggered moisture stress in media, where half irrigation was used, resulting in reduced plant growth and yield.

Under the full irrigation however, less water stress coupled with the ability of biochar to retain nutrient (reduces nutrient leaching) could have resulted in best growth for the 1 part of 2SS + 2 parts rice husk biochar x 0.255 mm irrigation interaction (Steiner and Harttung, 2014; Zhang *et al.*, 2014). The 2RH compost x 0.255 irrigation interaction was the worst treatment as it was observed to have had poor water holding capacity and water applied either saturate the media or quickly lost as leachate.

In the zinnia production, the 1 part of 2RH compost + 2 parts rice husk was best for zinnia plant height and flower head diameter, but worst in flower number, fresh biomass and flower stalk length. The 2SS compost was best for zinnia flower number and fresh biomass. The 1 part of 2SS compost + 2 parts rice husk biochar was best for zinnia dry weight and stalk length, but worst in flower head diameter. In the rice husk compost-rice husk biochar soilless media, plant growth and dry biomass increased with increasing addition of biochar (or decreasing nutrient as a result of diluting compost with biochar), whereas flower number decreased with increasing addition of biochar. This was in contrast to the finding of Kang and Van Iersel (2006) who reported that zinnia dry biomass increased with increasing nutrient concentration in soilless and that zinnia flower diameter decreased with increasing nutrient concentration. The implication of these findings is that once zinnia is less sensitive to EC and demand lower nutrient, it can be grown in low nutrient and higher EC compost, which may not be suitable for nutrient demanding and EC sensitive crops. The growth and yield response of lettuce as well as the flower quality of zinnia showed a huge potential for varying use of compost and biochar in soilless growing media. As biochar is carbon rich materials and compost is an N rich material, the simultaneous use of compost and biochar could optimize N and C balance in ways that can lead to better carbon sequestration in growing media. With reports of decreasing land availability in the urban areas for vegetable production, greenhouse production would have important application in urban horticulture. The use of soilless media can also help producers to avoid the problems associated with soils contaminated with weed seeds, pathogens and potentially heavy metals.

5.6 EVALUATION OF COMPOST-BIOCHAR MIXES FOR FIELD AND GREENHOUSE PRODUCTION OF VEGETABLES

In the present study, compost and biochar mixes optimised for field production of *Amaranthus* showed that sawdust compost and sawdust biochar mixes at a ratio of 1:2 were appropriate for field production in urban landscapes. Comparison of the sawdust and rice husk soilless substrate with an imported coir substrate (as control) indicated that the sawdust was able to outperform the coir between the 8 and 9 WAT. These results were consistent for both sweet pepper and runner beans in the greenhouse. This implied that the sawdust compost mixed with rice husk biochar (1:2) could be used to replace the imported coir substrate for soilless production of sweet pepper and runner beans. Acuna *et al.*, (2005) reported that the cost of production of soilless media can be reduced especially when local materials are used. Addition of biochar in the substrate increases the re-usability of the substrate (Fernandes *et al*., 2006; Giuffrida *et al*., 2007; Rea *et al*., 2008; Urrestarazu *et al.*, 2008).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study showed that the types of organic amendments used by urban horticulture practitioners were based on what was readily available to a specific location. Sawdust was more common in the southern Ghana and rice husk was more common in the northern Ghana. Composting these feedstock separately with poultry manure as the N source in various ratios was ready (mature) for use in 8 weeks. The study has also established compost maturity indices such as C:N ratio values, total N and mineral N levels, organic carbon, electrical conductivity and pH for the local materials used. Subsequently, standardised composts of different volumetric ratios of composted material and biochar mixes as a soilless media for both vegetables and ornamentals have been established.

Based on the various experiments thus far, 1-part composted rice husk (2RH) + 3 parts topsoil or 1 part of composted single species sawdust (2SS) + 3 parts topsoil were the best compost to soil ratio for vegetables especially EC sensitive plants such as lettuce. The 2 parts composted mixed species sawdust (2 parts sawdust: 1 part poultry manure) + 3 parts topsoil was the best compost to soil ratio for ornamental plants, especially EC tolerant plants such as zinnia. Sawdust compost (at 10 t/ha) + sawdust biochar (at 5 t/ha) was the best compost biochar mix for field production of vegetables. For soilless production system, the 1 part composted rice husk (2 parts rice husk: 1 part poultry manure) + 2 parts rice husk biochar was the best greenhouse soilless media for zinnia growth and flower quality. The sawdust compost + sawdust biochar in a ratio of 1:2 is standardised compost for greenhouse production of vegetables.

In Kumasi, it cost 0.36 and 0.41 Ghana Cedis (Ghc) to produce a kg of rice husk compost and sawdust compost, respectively. In Tamale the cost of producing a kg of rice husk compost and sawdust compost is 0.35 and 0.50 Ghc respectively. (Cost of production of composted rice husk was 0.01 Ghc less in Tamale where as composting sawdust was more expensive, 0.09Ghc more in Tamale than cost in Kumasi. Composting rice husk sjould be promoted in Tamale where as composting of sawdust shouls be promoted in Kumasi.

Finally the present study has clearly demonstrated that agro-industrial by-products such as sawdust and rice husk which are currently seen as nuisance and causing significant disposal challenges to urban authorities can be developed into nutrient rich composts for urban greening and urban horticulture, especially container production of vegetables and ornamental plants.

6.2 RECOMMENDATIONS FOR FURTHER STUDIES

1. Further work should be done on nutrient characteristics of both uncharred and charred sawdust and rice husk to support the findings of future research.

2. N rich compost especially those with higher EC such as 2SS compost should be used in lower concentration so as not cause injury to EC sensitive plants
3. When biochar is used as a bulking material in compost higher amount irrigation or more frequent irrigation cycle should be adopted.
4. Similar studies in the field should be studied for verification of the greenhouse experiments
5. Cost-benefit ratio of should be carried out for these amendments in vegetable and ornamental plants production
6. Effect of amendments on vase life of flowers should be investigated.

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APPENDICES

APPENDIX 1: SURVEY TO IDENTIFY ORGANIC AMENDMENTS AVAILABILITY FOR USE IN URBAN HORTICULTURE IN TAMALE AND KUMASI

Interview Schedule for horticultural practitioners

I. General information

1. Name of respondent: ________________________________

2. Respondent No. __________

3. Name of area: ___________________________________

4. District/Municipality_________________________________

5. Region____________________

6. How long have you used soil amendments (SA)? □ 5-10…………..□ More than 10 years

7. Knowledge sources:

Learned soil amendments on your own? □ Yes □ No, specify………………….

8. Farm characteristics a. Location: □ Backyard □ Urban open space

9. Land size/ No of beds (bed size): □ Less than 1/4 □ More than ¼

II. Producer profile

1. Gender: □ Male □ Female

2. Age: □16-35 □ More than 40

3. Education: Number of years in school: □ No formal education □ Less than 9 □ More than 9

4. Civil Status: □ Single □ Married

5. Minor occupation (occupation that gives additional income)

□ None □ Business

III. Details of Soil amendment used by producers

1. Please check ✓ the following soil amendment (SA) technologies that you are aware of. If you are aware of any technology, please indicate whether you use it or not (Column 2)? Please give your most limiting constraint in the last column.

SA technology	Aware of?	Using?		Most limiting constraint			
	Yes/No	Yes	No	Costly preparin g	Cheap	Unavailable Raw materials	Inability to prepare
Composted crop residues							
Poultry litter							
Cow manure							
Deco Compost							
Use of landfill waste							
Composted Sawdust							
Composted Rice husk							
Coco peat							
Accra Municipal Solid Waste compost							
Other (specify)…… …………							

2. Please check ✓as appropriate and fill in where necessary

SA	Source of soil amendment		Distance to farm		Means of transport	Cost per bag
	Owner prepare d	Supplier		1>5 - 5		

Composted crop residues						
Poultry litter						
Cow manure						
Deco Compost						
Use of landfill waste						
Composted Sawdust						
Composted Rice husk						
Coco peat						
Accra Municipal Solid Waste compost						
Other (specify)………						

3. Which of the following new combination of compost would you prefer?

□ Composted sawdust and poultry manure □ Composted crop residues and poultry manure

4. In what plots have you applied the introduced SA technology, please give detailed information.

Main plot number	Land size (ha.)	Main soil amendment applied in this plot	Quantity per land size		Main crop grown
			Any how	Recommended	

5. Strengths of soil amendment measures/practices that you have observed

□ None

□ Strengths observed, specify one_____________

6. Weaknesses of using soil amendment practice that you have observed
None
Weaknesses, specify one____________________

7. Opportunities for commercialising soil amendments None
Opportunities, specify one____________________

8. Threats for commercialising soil amendments
None
Threats, specify one____

9. General benefits for SA to you as a farmer…………………………………………………………………………………………
……

10. General problems you face in using soil

11. a. Is business progressing or retrogressing?
□ Yes □ No

b. If no, Why?..

c. If yes what is the percentage increase in income?

□ < 25 % □ >25 %

d. Main reason for increased income

□ Increased yield □ Increased demand for organic produce

APPENDIX 2: CORRELATION TABLES

Table 4.3 Correlations between farmers experimenting with compost and farmers adopting compost

			Trying out compost	Adopted composting
Spearman's rho	Trying out compost	Correlation Coefficient	1.000	.799**
		Sig. (2-tailed)	.	.000

	N	60	60
Adopted composting	Correlation Coefficient	.799**	1.000
	Sig. (2-tailed)	.000	.
	N	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between farmers experimenting with poultry manure and farmers adopting poultry manure

			Trying out poultry manure	Adopted poultry manure
Spearman's rho	Trying out poultry manure	Correlation Coefficient	1.000	.515**
		Sig. (2-tailed)	.	.000
		N	60	60
	Adoption poultry manure	Correlation Coefficient	.515**	1.000
		Sig. (2-tailed)	.000	.
		N	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

Cross tabulation relationship between education, district and level of awareness of compost

Variable	**B**	**SE**	**Wald**	**Df**	**Sig**	**Exp (B)**	**CI**
District	1.625	0.644	6.366	1	0.012	5.079	1.437-17.947
Education	1.913	0.844	5.132	1	0.023	6.773	1.294-35.44

Constant	-3.078	0.900	11.698	1	0.001	0.046

Correlations									
		EC	C02	pH	TN	0C	mg/kg NO3-N	mg/kg NH4-N	C:N
EC	Pearson Correlation	1	-.154	.229*	.018	.008	-.282**	.042	.034
	Sig. (2-tailed)		.094	.012	.843	.929	.002	.647	.713
	N	120	120	120	120	120	120	120	120
C02	Pearson Correlation	-.154	1	-.593**	-.449**	-.160	.663**	.033	.253**
	Sig. (2-tailed)	.094		.000	.000	.080	.000	.722	.005
	N	120	120	120	120	120	120	120	120
pH	Pearson Correlation	.229*	-.593**	1	.394**	-.039	-.683**	-.081	-.331**
	Sig. (2-tailed)	.012	.000		.000	.674	.000	.381	.000
	N	120	120	120	120	120	120	120	120
TN	Pearson Correlation	.018	-.449**	.394**	1	.301**	-.436**	-.179	-.817**
	Sig. (2-tailed)	.843	.000	.000		.001	.000	.050	.000
	N	120	120	120	120	120	120	120	120
0C	Pearson Correlation	.008	-.160	-.039	.301**	1	.151	-.257**	.188*
	Sig. (2-tailed)	.929	.080	.674	.001		.101	.005	.039
	N	120	120	120	120	120	120	120	120
mg/kg NO3-N	Pearson Correlation	-.282**	.663**	-.683**	-.436**	.151	1	-.061	.425**
	Sig. (2-tailed)	.002	.000	.000	.000	.101		.508	.000
	N	120	120	120	120	120	120	120	120
mg/kg NH4-N	Pearson Correlation	.042	.033	-.081	-.179	-.257**	-.061	1	.040
	Sig. (2-tailed)	.647	.722	.381	.050	.005	.508		.665
	N	120	120	120	120	120	120	120	120
	N	120	120	120	120	120	120	120	120

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).