EFFECTS OF CARBON/NITROGEN RATIO AND PARTICLE SIZE OF RICE HUSK AND SAWDUST ON COMPOSTING OF POULTRY MANURE AND THE PERFORMANCE OF *AMARANTHUS CRUENTUS*

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CERTIFICATION

I, Ekong, Ubong Johnson with registration number ASS/Ph.D/12/001, hereby certify that this work titled, "Effects of Carbon/Nitrogen Ratio and Particle Size of Rice Husk and Sawdust on Composting of Poultry Manure and the Performance of *Amaranthus cruentus*" is original, and has been written by me. It is a record of my research work and has not been presented before in any previous publication.

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DECLARATION

We declare that this thesis entitled "Effects of Carbon/Nitrogen Ratio and Particle Size of Rice Husk and Sawdust on Composting of Poultry Manure and the Performance of *Amaranthus Cruentus*" was carried out by UBONG JOHNSON EKONG with Reg. Number ASS/Ph.D/12/001 has been examined and found worthy of the award of the degree of Doctor of Philosophy (Ph.D) in Soil Science (Soil Fertility and Plant Nutrition).

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seasons. The highest heights at 8 WAT were obtained in plots treated with RH/BCW (1:16) 0.5 mm and RH/BCW (1:8) 0.5 mm in 2016 and 2017 cropping seasons, respectively. The widest stem girths were obtained in SD/BCW (1:16) 1.0 mm in 2016 season and RH/BCW (1:4) 0.5 mm in 2017 season, respectively. The broadest leaf areas were obtainedwith application of SD/BCW (1:16) 1.0 mm and SD/BCW (1:16) 2.0 mm in 2016 and 2017 seasons, respectively. The heaviest fresh leaf yields (11.47 and 9.47 t/ha) were obtained in plots fertilized with RH/BCW (1:1) 0.5 mm composts in 2016 and 2017 cropping seasons. The lowest fresh leaf yields (4.64 and 3.49 t/ha) were recorded by plants in the control in 2016 and 2017 seasons, respectively. Application of these compost treatments significantly increased the soil pH, the contents of major nutrients and decreased the C/N ratio of the post-planting soil (12:1 – 19:1) relative to the C/N ratio (23:1) of the pre-planting soil.

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CHAPTER ONE

INTRODUCTION

Soil fertility management is important for sustainable crop production.Poor soil fertility is one of the factors affecting sustainable crop production in sub-Sahara Africa (Omotayo and Chukwuka, 2009). The use of organic amendments in soil fertility management can reduce soil chemical degradation associated with the use of inorganic fertilizers and can also replenish soil nutrients for sustainable crop production.

In Nigeria, large quantities of food processing, wood and animal wastes are regularly and annually generated in increasing amounts. Rice husk from rice mills and sawdust from sawmills are often found in very large quantities forming dumps around the processing sites. Poultry manures are also found around poultry houses and sometimes large quantities of battery cage wastes are discharged into water bodies. Other raw materials used for the production of organic based fertilizers which are usually wastefully dumped are: neem plant/seed, city refuse, cow, pig dung, crop residues etc.According to Kalu*et al.* (2009), these wastes become a nuisance when they are disposed indiscriminately.

In regions where these wastes have become concentrated, excessive loading rates pose real problems such as the accumulation of nitrates in ground water and of phosphorus and nitrates in surface waters. In addition, high fly propagation and off site migration coupled with particulate and gaseous emissions from the dump sites have become significant environmental issues. These issues are major constraints and challenges to the profitability of agricultural sector (Place *et al.*, 2003) and as such mandates new approaches to wastes management.

Recycling of organic wastes through composting serves the dual purpose of cleaning the environment and providing economic benefits. The recycling of wastes is important for crop production and sustainable development. Rahman (2014) reported that organic fertilizer reduces expenditure on costly inorganic fertilizers which form more than 60% of the total production cost in agriculture in Nigeria.

During the past decades managers of livestock industries have become increasingly aware of environmental issues associated with the production, storage, treatment and utilization of animal wastes. The use of fresh poultry manure for growing crops has been a common practice in Nigeria. Poultry manure isrichorganic manure since solid and liquid excreta are excreted together resulting in no urine loss. The nutritional value of fresh poultry manure deteriorates rapidlyAbdulmaliq *et al.*(2015) hence, the need for immediate processing of poultry manure to prevent its rapid decomposition and save its nutrient properties. In addition, increased public consciousness of environmental pollution has challenged the agricultural Scientists to expand and to improve the disposal system, recycling the waste nutrients effectively. In recent times, composting of poultry manure has been shown to be useful in providing a stable end product without much loss of the nutrients in itself (John *etal.*, 1996; Amanullah*etal.*, 2010).

An alternative method to the current management of rice husk and sawdust wastes is composting. However, given their C-rich nature and high C/N ratio, adequate composting requires mixing with N-rich waste, such as poultry manure. A proper combination of carbonaceous and nitrogenous organic materials results in an ideal compost or effective and complete fertilizer. Vallini *et. al.* (2002) opined that some organic materials contain harmful mycelia, antibiotics, plant pests and excessive level of heavy metals, hence proper mixing and composting will lead to dilution and sterilization of such hazardous materials and will greatly promote the quality of the end product.

The importance of grain amaranth in human and animal nutrition, diversifying the food basket and industrial use as ink was earlier pointed out by Piha (1995). Apart from its edible value, it serves as effective therapy for hypertension and cardiovascular problems (Martirosyan, 2007).The yield per hectare of this crop is staked at 77.27 t ha^{-1} according to the United States, and the world average of 14.27 t ha^{-1}(FAO, 2007). To obtain optimum performance of *Amaranthus cruentus*, Egharevba and Ogbe (2002) reported that application of organic manure is needed. Therefore, this experiment was set up to determine the appropriate C/N ratio of different particle sizes of rice husk and sawdust on composting of poultry manure and theinfluenceof the composts on the performance of *Amaranthus cruentus.*This research wouldreverse the trend of indiscriminate disposal of rice husk, sawdust and poultry manure from battery cage systems among other organic wastes. Composting of rice husk, sawdust and battery cage waste could solve the problem of environmental pollution and also improve waste handling.Rice husk, sawdust and battery cage wastes are good sources of essential plant nutrients, therefore these composts couldimprove soil fertility and enhance growth and yield of *Amaranthus cruentus*.

1.1 Objectives of the study

The objectives of this study were to:

I. determine some contents of essential plant nutrients in the fresh composting materials and the resultant compost treatments at 4 and 8 weeks of composting.

II. determine the percent weight reduction in all the compost treatments at 4 and 8 weeks of composting.

III. determine the microbial counts in all the compost treatments at 8 weeks of composting.

IV. determine theeffects of the compost treatments on nutrient contents of*Amaranthus cruentus*at 9 WAT.

V. evaluate the effects of the C/N ratio and three particle sizes of rice husk and sawdust on the quality of theprepared composts and on the growth and yield of *Amaranthus cruentus.*

VI. evaluate the effects of all the compost treatments on soil properties at the end of the experiment.

biological process in which microorganisms of both types; aerobic and anaerobic decompose organicmatter and lowers the carbon/nitrogen (C/N) ratio. Brady and Weil (1999) reported that composting is the practice of creating humus-like materials outside of the soil by mixing, piling, or otherwise storing organic materials under conditions conducive for decomposition and nutrients conservation.Composts are important based on their nutritive value, which is fixed (except for N) by the initial compost mix. This is because the plant nutrients P, K, Ca as well as heavy metals, do not disappear from the system as the dry matter decomposes (unless leaching occurs). Nitrogen is lost through numerous pathways, with NH_3 being the most common. Epstein (2011) proposed strategies to minimize NH_3 loss: Air flow control, enclosure of the pile in a building or with semi-permeable covers and drying of the compost. As the compost moisture level drops the biological and chemical activity is inhibited, lowering the rate of transforming Uric acid → Urea → $NH_3 + CO_2$

Composting enhance 50 % reduction in mass and volume of composted materials (Chen *et al.*, 1992; John *et al.*, 1996).It also reduces the C/N ratio of materials in the process to prevent nitrogen immobilization (Chen and Inbar, 1993). Composting increase the soil cation exchange capacity (Ogbodo, 2012), and also destroys pathogens and weed seeds in the thermophilic phase (Turner *et al.*, 2005). Composting releases a wide range of essential nutrients and organic matter needed by plants (John and Udoinyang, 2007). Castillo (2004) also reported that composting increases beneficial microorganisms hence, encouraged microbial decomposition of the organic materials and the release of plant nutrients at the final stage.

2.2 Composting process

Composting process is viewed as a waste management strategy to stabilize municipal bio solids and organic urban wastes (Wolkowski, 2003). Composting process involves the conversion of organic materials in the presence of oxygen into organic fertilizer free from plant diseases and weed seeds that is capable of improving the health and quality of soil.Composting is the accelerated biological decomposition of organic materials in a predominantly aerobic environment. During composting process, microorganisms mediates in the transformation of organic materials into compost by decomposing the organic materials and converting them from organic form to inorganic form readily available for plants uptake (Levanon and Pluda, 2002). Some of the properties affected during composting process are the C/N ratio, CEC, pH, porosity, bulk density and acidity/or salinity of compost.

Composting process requires soil microorganisms, organic materials, moisture, temperature and aeration. During the process, microorganisms break down organic materials to stable, usable organic substances called compost. The process consumes oxygen and releases heat, water and carbon dioxide (Haug, 1993). Under controlled conditions, the composting process is described in terms of primary (high rate composting), secondary (compost stabilization), and curing phases. The primary phase is where most of the organic breakdown occurs and high temperatures are achieved. The secondary phase has lower biological activity resulting in slower composting and lower pile temperatures. During the curing stage, mesophilic bacteria colonize the compost. The length of time for any one phase of composting or curing will be affected by the input and processes parameters such as temperature, moisture, oxygen levels, C/N ratio, particle size and management practices like frequent turning and watering.

However, Lampkin (1990) stated that composting process is in four stages, that is, the mesophilic stage, thermophilic stage, cooling-down stage and maturing stage. The mesophilic stage in composting processharbour mesophilic strains of microorganisms that are present in the organic materials and the environment. When this microorganisms start to decompose the materials, heat is produced and the temperature of the compost heap rises, while pH increases as organic acids are produced. Ishii *et al.* (2000) reported that the succession of mesophilic and thermophilic microorganisms in composted materials is connected with temperature changes. As the temperature of the compost heap rises above 40°C, the thermophilic strains take over and the temperature rises to 60°C, where fungi become deactivated. According to Janda and Falkowski (2003), thermophilic microorganisms possess the ability for growth and development in conditions of high temperatures. As the temperature keeps rising, the process continues with mainly the actinomycetes and spore-forming bacteria being active. At this point, sugars, starches, fats and proteins are completely broken down but the rate decreases as the more resistant materials are attacked which leads the process into the cooling-down phase. As the temperature drops, the thermophilic fungi re-colonize the heaps. Wieland and Sawicka (2000) reported that with the temperature drop below40 °C the number of fungi in the composted mass increased and begin to attack the cellulose creating way for the mesophilic strains of microorganisms. The final stage leads to the breakdown of residual organic matter to a stable product of humus or humic acids. During this period, antagonism and antibiotic formation set in, and the compost is invaded by macro-fauna which contribute to further breakdown of the organic material by maceration of the particles.The ease of degradation of compounds in compost is in the order: carbohydrate > hemicellulose > cellulose = chitin > lignin. Composting material is placed in a windrow (pile) and is turned at regular schedules. Pile heights are generally limited to 1.5 – 2.5m because of the ability of equipment to handle material and porosity considerations. Moreover, Luangwilai *et al.* (2010) reported that if the compost pile is too small, its temperature remains in the low temperature region which is not ideal for biological reaction whereas, for a larger compost pile, the temperature is able to rise to the desirable range for biological reaction.

Materials flow in a composting system depict that for maximum composting rates, primary ingredients, amendments and recycled compost are mixed to achieve optimal ranges for initial C/N (20 – 40), moisture (45 – 65%), porosity (30 – 50%), and other factors. Then the mix is put into a pile or windrow where the composting process occurs. Depending on the system and phase, the mix gets turned daily, every 3 – 4 days or sometimes only weekly or monthly. In some systems, air is allowed to pass through the compost to control temperature. When little or no heat output is observed,Seyedbagheri (2010)opined that the material is confirmed to be cured.

During the composting process temperature changes occur within the pile of organic matter, the volume of the compost pile decreases considerably and the pH initially becomes acidic, then alkaline and finally near neutral. The chemical constituents are modified to various degrees, in the end resulting in a complex of organic material commonly known as humus.

two drops of liquid expelling from the compost sample but when it is too dry the compost will crumble in the hand. Hence the compost windrows should be turned with addition of water during the process and the seepage from the compost should be mopped with the dry portion of the compost material.

During normal composting moisture level decreases unless water is added. Decrease in moisture content can reduce decomposition rates even further than at the start of the process. Rynx (2000) also mentioned that the critical moisture content for composting is around 20 to 45%; above this range there is moisture sufficient for the evaporation process to cool the temperature and below it there is insufficient moisture to sustain the biological reaction. There is a high degree of water loss from a compost pile during the composting process, therefore spraying the piles with water to maintain a range of 40 – 50% moisture content encourages microbial growth. Lampkin (1990) reported that the ideal moisture content for composting was in the range of 55 – 70%. The reduction in the value of moisture content at the end of composting is a positive sign of decomposition and the moisture is inversely proportional to the temperature and the microbial activity (Makan *et al.*, 2012).

2.3.2 Temperature

The temperature factor is important determinant of the changes occurring in the composting process. Initially, the composting mass is at ambient temperature, but a rapid rise occurs as the microorganisms multiply. John and Ijah(2012) reported a sharp increase in cattle dung/poultry manure compost temperature from 43 to 47 °C during the first two turnings and then increased gradually during the second week. They added that the temperature stabilized at third week after which it began to drop to near ambient temperature at the end of the composting. According to Fonstad*et al.* (2003), a convenient and meaningful compost parameter to monitor is temperature because it is a key indicator of the state of composting process and microbial activity. Increase in temperature is brought about by microbial activities due to the consumption of easily degradable organic compounds and it occurs within few hours to days depending on the contents of organic materials available for decomposition. The highest rate of decomposition occurs at temperatures in the range of 43 to 66 °C while pathogens kill may be achieved if temperatures rise above 55 °C for three consecutive days (Keener and Elwell, 2003). The temperatures are observed in the middle of the pile and are characteristic of the large and small piles. Large compost piles generate more heat and maintain high temperatures than smaller compost piles as confirmed by Luangwilai *et al.* (2010).Temperature gradient from the centre ofthe compost outward is reduced as the pile size increases because heat loss is proportional to surface area and heat generation is proportional to the volume, the larger pile having a smaller surface area to volume ratio loses relatively less heat. The temperature of wastes mass decreased with increase in incubation time. Mina *et al.*(2012) reported a maximum temperature of 49 °C for compost with particle size of 10 - 20 mm at 14 days of composting. They added that the temperature of the wastes mass decreased and stabilized at 18°C after 161 days of composting. The increase in temperature is rapid, usually 50 --60°C within few days of composting and gradually drop to between 38 – 43 °C and finally drop to ambient air temperature when the process has finished.The temperature pattern shows the microbial activity and the occurrence of the composting process (Bernal*et al.*, 2009). When the temperature exceeds 40 °C, the mesophilic stage is replaced by the thermophilic stage. The time required to reach the thermophilic stage varies, but it is achieved in 2 or 3 days of composting, decomposition of organic matter is faster in the thermophilic stage. The highest decomposition rates occur when temperatures are high and greater level of oxygen uptake is attained. Compost heaps should be porous enough to enhance adequate aeration for faster decomposition. High compost temperature in the thermophilic stage of composting destroys the viability of pathogens and weed seeds and break down phytotoxic compounds in the finished composts; temperatures above 70 °C microorganisms are killed, at the range of 55 - 70°C pathogenic microorganisms are inactivated, at the range of 50 - 60°C weed seeds are inactivated and below 40°Ccomposting process is slowed down (Keener and Elwell, 2003).

The decomposition rate in a biological system is considered to be a function of temperatureor a linear form known as temperature coefficient which states that for every 10-degree plus increase of temperature in the composted materials, there is a successive drop or increase in the proliferation of microorganisms which confirms the observation of Hassen *et al.* (2001) who noticed the decrease of proliferation of mesophilic bacteria with the increase of temperature in the compost pile. Most researchers agree that 55 – 65°C will lead to maximum decomposition rates but the optimum temperature range for composting is between 40 - 65°C. Optimum composting temperatures are achieved by controlling pile size and/or regulating air flow and allowing heat generated through microbial activity to leave the pile. Depending on the physical and chemical properties of the composted organic material and other determinants of organic decomposition, the compost temperatures normally range from value higher than air temperature to about 75°C. Different types of aerobic bacteria work in composting piles under varyingtemperature range. Psychrophilic bacteria can work in the lowest temperature range and are most active at 13°Cgiving *al.*,2003). At high C/N ratio above 30:1the rate of compost breakdown will decrease. At too low C/N ratio where high contents of nitrogen are recorded, this N may be lost as ammonia (NH_3) to the atmosphere (Azim *et al.*, 2014) in the process of volatilization thereby producing smelly odour usually perceived during composting process. Moreover, poultry manure with C/N ratio lower than 20:1 (Adhikari *et al.*, 2008; Sundberg *et al.*, 2011) and moisture higher than 70%, affect negatively the processing time, transformation rates and quality of the obtained product. Additionally, decomposition of poultry manure could generate greenhouse gases (Yang *et al.*, 2013).If, however, the system experiences large nitrogen losses, the C/N ratio can be increase (Li *et al.*, 2013) by addition of bulking materials such as sawdust and rice husk to modify physical properties of the substrates, improve biological activity and acts as source of carbon. Determination of the C/N ratio in composting materials may be difficult for the peasant farmers. To achieve the ideal ratio of 30:1, one part of carbonaceous material with two parts of nitrogenous material to supply adequate N for rapid mineralization of essential nutrients is recommended.

Significant ($P<0.05$) differences were reported in the growth of maize (*Zea mays*) in acid sands soil at Universityof Uyo Teaching and Research Farm (Effiong *et al.*, 2012) cultivated under palm kernel cake (PKC)/sawdust (SD) compost treatments with C/N ratio of 53:1 for SD and 21:1 for PKC. The effect of swine waste with C/N ratio of 16:1 combined with sawdust that recorded a high C/N ratio of 64:1 composted for 10 weeks was reported by (Ekong *et al.*, 2017) to significantly ($P<0.05$) increase the growth parameters and the yield of eggplant (*Solanum aethiopicum*) in acid soils of Obio Akpa, Akwa Ibom State.Mina *et al.* (2012)evaluated the effect of particle sizeand composting period on C/N ratio of Date-palm waste and reported that organic carbon content in wastes reduced in 0 -5 mm particle size compost than in 10 – 20 mm particle size compost. On the other hand, total nitrogen increased in 10 – 20 mm particle size compost than in 0 – 5 mm compost. Several other experiments carried out with organic materials of varying C/N ratios mixed and composted together showed significant changes in the growths and yields of diverse crops.Onwudike *et al.* (2015) reported that rice mill waste with C/N ratio of 28:1 combined with poultry manure decreased the C/N ratio of post-planting soil than sawdust with C/N ratio of 71:1 combined with the same poultry manure. They concluded that combined application of poultry manure with rice mill waste or sawdust improved soil quality, growth and yield of maize in acidic soils of Owerri. According to Wahab *et al.* (2017), application of poultry manure compost with C/N ratio of 5:1 at the rate of 20 t/ha enhanced better performance in growth and yield of two tomato varieties in Abeokuta. It is therefore important to know the C/N ratio of organic resources used in composting process before using such materials for composting because the rate of decomposition of organic materials increases with decrease in the C/N ratio. Agbede (2009) reported that at C/N ratio below 20:1, mineralization of N through nitrification is high but above this ratio the microbes incorporate the N into their bodies and at that point N is immobilized.

2.3.4 Particle size

The particle size of organic materials affects the composting period and the quality of the finished compost.According to Faatih *et al.* (2008), microbes play an important role in reducing the particle size of organic materials at the mesophilic phase. Particle sizes are critical for balancing surface area for the growth of microorganisms and maintenance of adequate porosity for aeration. Particle size of materials to be composted can speed up the decomposition process by increasing their surface area and hence their susceptibility to microbial invasion, so reducing the size of materials will increase the surface area and promote microbial activity and accelerate the composting process. Large size particles reduce surface area of composting materials for microbial attack (Zia *et al.*, 2003) which slows down or may stop composting process altogether.

The rate of aerobic decomposition is increased with smaller particle size. However, very small particles pack tightly together (Shirani *et al.*, 2013) can prevent movement of air into the composting heaps and movement of carbon dioxide out of the heap.Therefore, particle size might double the amounts of evolved CO_2 as compared to the unground material and a better initial aeration is also achieved due to increased availability of oxygen at particle surfaces.In addition, the particle size ensures that the material is more easily handled and moistened. Studies on particle size suggest acceptable values of 0.8 – 1.2cm nominal diameter for effective composting process. However, Gomez-Munoz*et al.* (2012) reported that the fraction smaller than 0.5 mm, and in particular between 0.1 and 0.25 mm had the highest influence on porosity and water retention. For poultry manure, particle size would not be an issue if moisture is <45% at the start of the process and mechanical mixing is used during or at the end of the process to eliminate clumping of materials to produce a granular product. For a successful composting process of any kind, theparticle sizes of the composted organic materials determine the duration of the process and the quality of the end product.Earlier report by Gray *et. al.* (1981) stipulated two months for fine particles and three months for coarse particle organicmaterials and two to three months for mixed particles as the minimum time required to produce mature compost.

Particle size of composting materials affects the rate of decomposition of the material. The more the available surface area of organicmaterials(Insam and De-Bertoldi, 2007) the higher the rate of decomposition of the materials by microorganisms because most of the activity occurs at the interface of particle size. Microorganismscan decompose smaller pieces of materials faster than the coarse bulky materials. Although tiny pieces of material use in composting may compact and impede aeration in compost pile hence, they can be chopped, shredded, bruised or punctured to increase the surface area. Shirani and Ahmad (2013) reported that smaller particles have larger surface area than those with larger particles; a larger surface area allows the compost to hold more moisture and to increase water holding capacity which causes poor air-water relationship, leading to low aeration within the compost pile. Compostingmaterials with large particle size possess large air pockets,therefore such compost piles do not heat up easily and such condition inhibits rapid decomposition of organic materials in composting process.

Organic materials with medium to coarse texture, equivalent to particle sizes distribution between 0.25 and 2.5 mm was reported by Benito *et al.* (2005) to be the best as this allow retention of enough available water together with adequate air content. Hachicha *et al.* (2008)reported that higher surface area in smaller particles caused more decomposition of organic matter and more production of organic acids. Abad *et al.* (2001) observed the highest amount of EC (6.29 dS/m) in smaller particle sizes of organic manure than others and attributed that to increased dissolution of solutes, they also observed highest amount of CEC in smaller particle size manure due to larger surface area. Sureshkumar and Ganesh (2012) observed increased microbial activity and elevated level of Ca and Mg content in 0.01 – 0.1 mm particle size organic manure than in 0.1 – 1.0 mm and 1.0 – 2.0 mm particle sizes of organic manure. Similar report by Jenny and Malliga (2014) stipulated that minimum particle size (0.01 – 0.1 mm) of organic manure enriched nutrient status of soil and also induced plant growth and gave good yield of tomato plants compared to other particle sizes and the control. Loehr (2010) also reported that different particle sizes of palm wastes had significant effect on N, P, K, Ca, Mg and Fe and concluded that the highest concentrationsof the listed elements were related to particle size of 0.5 – 1.0 cm than in other higher particle sizes.

2.3.5 pH control

The pHof organic materials is one of the important factors in composting process.The pH of municipal solid waste was reported by (Krogmann *et al.*, 2010) to be alkaline and it ranged from 7 – 8 while that of bio-wastes was acidic in the range of 5.7 and 5.4. The pH between 5.5 and 8.0 supports good microbial activity during composting. Specifically, pH value ranging from 6.0 - 7.5 is fit for bacterial development while the range of 5.5 – 8.0 is suitable for fungi growth. Acidic pH values could inhibit the growth of microorganisms (Li *et al.*, 2013) as well as determine the relative reactions of some substrate components. The pH of periwinkle shells, horn/holf meal and clam shells were reported by (Jonh *et al.*, 2003) to be 6.34, 7.86 and 8.53, respectively in their study to evaluate the organic substances for use in the production of organic and organo-mineral fertilizers in Uyo.

The pH affects loss of nitrogen where large quantities of nitrogen will volatilized in the form of ammonia (NH_3), if the pH is not maintained below 7.5. The pH rise was linked to the biodegradation of organic acids, mineralization of organic compounds (Paredes *et al.*, 2000) and the consequent release of volatile NH_3. Poultry manure has a high pH of 7.5 – 8.9, so would be expected to lose a high percentage of its N as NH_3–N. There are fluctuations in the pH value of compost throughout the period of composting. The temporary drops in pH noticed during composting (Charest and Beauchamp, 2002) were attributed to the production of organic acids during decomposition of organic matter contained in the mixtures. The decrease in pH at the later stage of composting (Eklind and Kirchmann, 2000) may be linked to the volatilization of ammonia nitrogen and H^+ released as a result of microbial nitrification process by nitrifying bacteria. Alkaline pH values were observed after four days of composting (Sundberg and Jonsson, 2005) which could be associated with biodegradation and consumption of organic acids formed by the microorganisms with subsequent increase in the pH of the compost. Moreover, the release of CO_2 during aeration process in the compost (Haug, 1993) prevents the formation of carbonic acid and its derivatives, thereby increasing the pH of the compost.

The alkaline pH values could be associated with high (K^+) content in such substrates. Kalemelawa *et al.*(2012)observed that this metal in its water-soluble formcan combined with (HCO_3^-) ion generated during the organic material mineralization step to form a strong base (KOH) responsible for alkaline pH observed. Ayesha *et al.* (2016) reported that alkaline pH is important parameter to evaluate compost maturity and stability. The mean pH values of compost treatments at 0, 4 and 8 weeks of composting were reported (John and Ndoh, 2004) to be 8.42, 8.41 and 8.43 for bare, covered and shaded composts, respectively when they evaluated the effects of shading types on the nutrient contents of municipal solid waste plus poultry manure in Ikot Ekpene, Akwa Ibom State. Effiong *et al.* (2012) reported the pH range of 6.2 – 6.8 at 4 weeks of composting palm kernel cake/sawdust and another range of 6.1 – 7.4 at 8 and corn stalks subjected through mesophilic, thermophilic and curing degradation phases in Beijing, China.

2.3.7 Porosity

Porosity refers to the amount of air-filledpore space in compost that is not occupied by solid particles or water. Air-filled porosity in a composting mixture should support microbial activity and enable adequate oxygen supply. Mohee and Mudhoo (2005) reported that the optimal air-filled porosity in the range of 30 – 60% of total volume results in optimal moisture content of 50 - 60%. The pore spaces are meant for air circulations that supply oxygen to the organisms. Berhte *et al.* (2007) observed that the initial air-filled porosity of 23% did not provide sufficient amount of oxygen for microorganisms. The optimal values (Kulcu and Yalidiz, 2007) seem to be in the range of 30 – 36%. Porosity is positively correlated to the particle size of the composting material.Materials with fine particle sizes can impede air circulation, therefore composting of fine textured materials with coarse textured materials is recommended.Annan and White (2009) reported that the optimal level of air-filled porosity was between 30 and 60%. Other authors (Michel *et al.*, 2004; Berhte*et al.*, 2007) reported that values below 60 – 65% provided proper performance of composting. Compost porosity >30% is important to minimize anaerobic conditions since windrows, as with static piles, depend on natural convection (chimney effects) to ventilate the pile. Optimal porosity for aerobic decomposition as reported by Ahn *et al.* (2008) was 85 -90%. Excessive porosity (>70%) can prevent the compost windrow from self-heating. However, Michel *et al.* (2004) stated that air-filled porosity higher than 75% was excessive and did not allow thermophilic temperatures. Windrow systems often generate some odours early in the process with highly putrescible material. One method to minimize odour is to keep the pile temperature below 58°C which can be accomplished by regulating pile size, moisture content and porosity. Another method is to cap the piles with a bio-filter material to trap escaping odours and delay turning the compost windrows until the temperature of the high rate phase of composting has declined to <58°C and oxygen levels have recovered in most regions of the pile. It has been observed by Mohee and Mudhoo (2005) that the initial moisture content of 60 – 65% allowed air voids of 30 – 40% during the curing phases of composting process.

2.4 Organic materials and their nutrient contents

It is important to be familiar with the materials used for composting. Organic materials are obtained from either plant or animal source, including livestock manure, green manure, crop residues, household waste, and works directly as a source of plant nutrients and indirectly influences the physical, biological and chemical properties of soil. Different organic materials have diverse level of nutrient contents but of the many elements required for microbial decomposition, carbon and nitrogen are the most critical.

2.4.1 Poultry manure

There are different types of poultry manure; deep litter, broiler house, battery cage and deep pit or high rise manures. In this context emphasis is placed on battery cage manure which is chicken excreta without bedding materials usually obtained from a battery cage system. Manure obtained from battery cage system contains 60 – 70% moisture, making the process of application difficult. At the same time, Overcash *et. al.*(1983) earlier reported that if the poultry manure from battery cage system is stored to reduce the moisture content, severe losses of essential plant nutrients occur and handling cost increases. Another problem peculiar to this manure is that nitrogen (N) is too quickly available so that, if care is not taken in applying it, burning occurs. Generally, poultry manure (Agbede *et al.*, 2017) contains all the essential plant nutrients that are used by plants and Mullins (2002) listed some of the nutrient elements; nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, manganese, copper, zinc, chlorine, boron, iron and molybdenum. However, properties of poultry manure (Fulhage, 2000) are highly variabledepending on the age, moisture content, feed formulation and physiological status of the birds.

Propertiesof poultry manure recorded by Amanullah *et. al.* (2007)are 8 - 8.3 pH, 35 – 38% C, 3 - 3.9% N, 9.7 - 11.6 C/N, and 17.8 - 19.7% ash. Nutrient content of battery cage manure by the same authors are C/N ratio (5.8 – 7.6), total N (3.63 – 5.30%), total P_2O_5 (1.54 – 2.90%), total K_2O (2.50 – 2.90%), Fe (970 -1450 $mgkg^{-1}$), Zn (290 - 460 $mgkg^{-1}$), Cu (80 – 172 $mgkg^{-1}$), Mn (370 – 590 $mgkg^{-1}$), Ca (0.80 – 1.02%) and Mg (0.40 – 0.56%).Emede *et al.*(2012) gave the contents of poultry manure as 15.50 gkg^{-1} organic C, 13.4gkg^{-1} total N, 0.49 gkg^{-1} available P, 3.40gkg^{-1} Ca, and 0.9$gkg^{-1}$for this three basic cations (Mg, K and Na). Ayoola and Adebayo (2017) reported on the chemical composition of poultry manure to be pH (5.1), N (4.1%), available P (2.4%), organic carbon (13.76%), K (2.67%), Ca (3.17%), Na (1.67%), Mg (3.23%) and Fe (1.97%). Properties of poultry droppings used by Ekundayo and Olayinka (2016) to evaluate the effects of application of compost and inorganic P on soil chemical properties and maize growth in an ultisol of Ile-Ife in Ogun State weregiven as follows; pH ($CaCl_2$) 6.1, organic carbon 4.0%, total N 0.56%, C:N 8:1, total P 0.22%, C:P 18:1, K 0.22%, Ca 0.36%, Mg 0.33% and Na 0.33%.

Belay *et al.* (2001) reported that poultry manure is an excellent soil amendment capable of releasing essential plant nutrients and improving soil fertility status by activating soil microbial biomass.The contents of poultry manure were reportedas 45 - 75% dry matter, 26 - 36 gkg^{-1}NH_4-N, 33 – 56gkg^{-1} total N, 45 - 48gkg^{-1} P_2O_5 and 30 - 35gkg^{-1} K_2O, also when poultry manure was applied at the rates of 0, 2, 4, 8, 10 and 15 t/ha to *Amaranthus cruentus*, the highest plant stand, height, leaf count and stem girth were observed with the application of 15 t/ha (Agbede *et al.*, 2017).Poultry manure is found to support root development and increase crop yield (Abou El-Magd*et al.*, 2006).Incorporating organic fertilizer into the soil for crop production is expected to play a direct role in plant growth as a source of all necessary macro- and micronutrients in available forms during mineralization, thereby improving the properties of the soil. Linger and Critchdey (2007) stated that the use of poultry manure as fertilizer input improves the physical, chemical and biological properties of the soil.

Afolabi *et al.* (2017) reported on the effects of application of 120 kg N ha^{-1} of poultry manure on some chemical properties of soilsin Niger State and the influence of the application on the grain yield of maize in two locations. They gave value of soil nutrient content as influenced by poultry manure application as follows; total nitrogen (1.05 g/kg), organic carbon (5.30 g/kg), available P (12.44 mg/kg), exchangeable K (0.33 cmol/kg) and yield (3.50 t/ha) in Minnasoil and total nitrogen (0.30 g/kg), organic carbon (5.20 g/kg), available P (6.32 mg/kg), exchangeable K (1.95 cmol/kg) and yield (2.71 t/ha) in Anyigba soil meaning that the application had significant effect on soil chemical properties and yield of maize in the two study sites.

The chemical composition of poultry manure was also reported by Iren *et al.* (2015) when theyinvestigated the residual effects of integrated use of organic manure and NPK fertilizer on soil properties of Akpabuyo in Cross River State and the growth of cassava. The chemical properties of poultry manure were 4.33% total N, 1.44% total P, 0.68% total K, 3.20% Ca, 0.60% Mg and 29.3% organic carbon. They reported that treatment application had significant residualeffects on almost all the chemical properties of the soil with the highest values for exchangeable Ca, Mg, ECEC and base saturation when 7.5 t/ha of poultry manure + 300 kg/ha NPK was applied relative to other treatments.They added that soil organic carbon content and soil pH were significantly increased in plots treated with organic manure alone. Theyconcluded that sole application of poultryand pig manures and their combinations with NPK fertilizer had high residual effects on soil nutrient.Deksissa *et al.* (2008) reported that poultry manure also contains high content of organic matter (9.14 g/kg)that can improve the soil structure, nutrient retention, aeration, soil moisture content,water infiltration and other physical properties when it is applied in the right amount and quantity.

2.4.2 Rice husk

Rice husk is the outermost layerencasing a rice grain obtained during the milling process.Rice husk is carbon rich waste derived from rice agro-industry.Okonkwo *et. al.* (2011) gave the nutrient contents of rice husk dust with values of organic carbon (24.17 gkg^{-1}), organic matter (41.66 gkg^{-1}), nitrogen (1.50 gkg^{-1}), C/N ratio (16:1), phosphorus (7.46 gkg^{-1}), calcium (0.98 $cmolkg^{-1}$), magnesium (0.32 $cmolkg^{-1}$) and potassium (0.54 $cmolkg^{-1}$). Rice husk contains about 75% organic volatile matter and the balance 25% of the weight of this husk is converted into rice husk ash during the firing process. The rice husk ash (Alhassan, 2008) in turn contains about 85 – 90% amorphous silica. The moisture content of rice husk ranged from 8.68 to 10.44%.

When crop residues are returned to the soil(Ewulo, 2005) they are beneficial for the maintenance and improvement of the physical, chemical and biological properties of the soil by enhancing easy tillage, crop growth and yield. Rice husk as one of the crop residues, is relatively cheap, affordable and readily available around the processing sites.The chemical properties of rice husk were reported by (Ogbodo, 2012) as organic matter (4.11%), pH (5.44), N (0.17%), P (34.07 mg/kg), K, Ca, Mg, Na and ECEC (0.28, 19.57, 8.27, 0.19 and 29.45 cmol/kg), respectively and base saturation (93.13%). Ogbodo (2012) further stated that rice husk + poultry manure had the highest pH value in soil of Ebonyi State University compared to other treatments. Combined application of poultry manure with either sawdust or rice husk (Onwudike *et al.*, 2015) proved more effective in improving soil quality, growth and yield of maize in acid soils of Owerri. Nutrient composition of rice husk waste was reported by Nwosu and Chikere-Njoku (2015) to be 1.05% N, 0.65% P, 0.85% K, 4.42% Ca, 1.52% Mg, 0.39% Na and 44.80% organic carbon and observed that rice husk waste with high mineral elements (K, Ca and Na) is capable of improving the buffering potentials of ultisol of Owerri in Imo State for sustainable maize production.

2.4.3 Sawdust

Sawdust is tiny particles of wood that are formed from sawing or sanding wood. Sawdust could come from soft or hard wood and their chemical composition varies depending on the nature of wood it is obtained. Donahue *et al.* (1990) reported that fresh sawdust, wood and wood chips have an average composition of 0.1% N, 0.04% P, 0.017% K and a carbon/nitrogen (C/N) ratio of 500:1 in dry weight basis.Effiong *et. al.* (2012) reported a C/N ratio of 53:1 for sawdust derived from soft woodand 24:1 for palm kernel cake which reduced to 10:1 – 18:1 at eight (8) weeks after composting (WAC) when palm kernel cake/sawdust were prepared in four composting ratios (1:1, 2:1, 4:1 and 8:1) to evaluate the effects on maize growth in acid sands soil in Uyo. They also reported on other nutrients in the four compost treatments at 8 WAC to be pH (6.1 – 7.4), EC (1.348 – 1.998 dS/m), organic carbon (284.4 -398.2 g/kg), total N (22. 0 - 30 g/kg), P (2201 – 2441 mg/kg), Ca (1002 – 1812 mg/kg), Mg (1034 - 1154 mg/kg) and K (1335 – 1811 mg/kg) and substantial amount of micronutrients. Similarly, Ogbodo (2012) reported the chemical properties of sawdust as follows: organic matter (5.06%), pH (5.22), nitrogen (0.28%), phosphorus (41.70 $mgkg^{-1}$), potassium (0.20 $cmolkg^{-1}$), calcium (20.77 $cmolkg^{-1}$), magnesium (8.93 $cmolkg^{-1}$), sodium (0.25 $cmolkg^{-1}$), effective cation exchange capacity (ECEC) (30.86 $cmolkg^{-1}$) and base saturation (97.7%).

The chemical composition of fresh sawdust was reported by Ekong *et al.* (2017) to contain pH (6.20), electrical conductivity (43.6 dSm^{-1}), organic matter (288 gkg^{-1}), total N (2.6 gkg^{-1}), C/N ratio (64:1) and Ca, Mg, Na, K, P, Cu, Mn, Zn and Fe as 3660, 721, 90.3, 3320, 203.3, 62.1, 80.3, 123 and 1.5 $mgkg^{-1}$, respectively. Sawdust can be used as soil amendment because it contains and can release essential plant nutrients such as N, P, K, Ca, Mg and micronutrients (Awodun and Ojeniyi, 2007; Ewulo *et al.*, 2009). However, sawdust does not decompose easily along with other organic materials because of the high content of cellulose.Several authors found that sawdust compost could improve performance and nutrients availability in production of maize, amaranthus, tomato, pepper (Ojeniyi and Adejobi, 2012; Owolabi *et al.*, 2003). Chemical analysis of sawdust ash (Babadele *et al.*, 2013) revealed low content of N (0.27%) and P (0.10%) but higher in K (5.8%), Ca (1.8%) and Mg (0.48%).

The rice husk and sawdust acts as bulking agents for the poultry manure during a composting process. The bulking agents also called the bulking particles are very effective to regulate the air supply, moisture and other important composting parameters. The particle sizes of bulking agents affect the time required for composts maturity(Mina *et al.*, 2012) and the quality of the cured compost. In recent years bulking agents received much attention because of efficiency and usefulness in composting, pollution control and waste management.

2.5 Effects of organic amendment on*amaranthus cruentus* performance

Amaranthus cruentus (Linnaeus), commonly called smooth amaranth, smooth pigweed, red amaranth, green amaranth or slim amaranth, is a popular leafy vegetable cultivated in almost all parts of Nigeria and many parts of the World. It is eaten as a vegetable in almost all parts of Nigeria including Akwa Ibom, Cross River, Delta and Edo States as well as South western and Northern states.*Amaranthus cruentus*(Mnkeni *et al.*, 2006) is highly nutritious and fast growing, cheap and rich in nutrients such as minerals, vitamins, water, sugar, protein, calcium, thiamine, riboflavin and fibres with antioxidant properties. One of the problems encountered by amaranth growers is inadequate supply of inorganic fertilizers and lack of finance to buy the fertilizers (Olufolaji *et al.*, 1990). It was observed (Akparobi, 2009) that high quality amaranth can be made available at reduced price when organic manure is used. Application of organic manure can sustain crop yields under continuous cropping through gradual nutrients release to improve the fertility of degraded soils

(Mbonu and Afrifalo, 2006) and it was reported by Egharevba and Ogbe (2002) that organic manure has been found to sustain yield under continuous cropping and improve the fertility of a degraded soil.

Amaranthus cruentus requires high amount of nitrogen (Adeoye *et al*., 2005) which is limited in the tropical soils however, nitrogen can be sustainably added to the soil through compost. Fademi *et al*.(2017) reported a positive effect of compost tea made from poultry droppings, cow dung and water leaf on post-harvest soil properties and yield of *Amaranthuscruentus*. Ojo and Obigbesan (1999) gave the optimum rate of phosphorus for leaf dry-matter yield of grain amaranth (51.8 kg/ha P) and (48.4 kg/ha P) for grain yield.The mineral composition of *Amaranthusspinosus*leaf treated with organic fertilizer was presented by Mofunanya *et al.* (2012) to be Mg (4.45 ± 0.3 g/100g), Cu (0.03 ± 0.2 g/100g), Zn (0.03 ± 0.1 g/100g), K (7.60 ± 0.1 g/100g), Fe (0.12 ± 0.02 g/100g), Ca (2.94 ± 0.2 g/100g), Na (6.50 ± 0.03 g/100g) and P (0.43 ± 0.1 g/100g), respectively.The comparative effect of organic and inorganic fertilizers on mineral composition of *Amaranthusspinosus* leaf, stem, root and inflorescence revealed that organic fertilizer produced higher effects on all the parameters investigated when compared with inorganic fertilizer and this results are in agreement with the previous researchers who have reported increases with organic fertilizers on some proximate and mineral contents (Makinde *et al*., 2010; Funda *et al*., 2011).Proximate composition of *Amaranthus cruentus* in (g/100g) as revealed by Emmanuel and Folasade (2011) are moisture content (7.6 ± 0.6), crude protein (34.8 ± 1.1), crude fat (9.6 ± 0.02), carbohydrate (29.0 ± 0.4), total ash (17.2 ± 0.01), crude fibre (1.7 ± 0.15) and energy (KJ) (1441.7 ± 13.2). They also gave the mineral composition of *Amaranthus cruentus* in (g/100g) as sodium (32.3), calcium (50.2), potassium (11.6), magnesium (11.6), iron (5.2), zinc (7.5), phosphorus (45.7) and manganese (0.08).

When poultry manure was cured for two weeks and incorporated into the soil at the Teaching and Research Farms of University of Benin at the rates of 0, 5, 10, 15 and 20 t/ha two weeks before transplanting of *Amaranthus cruentus*(Emede *et al.*, 2012) observed that there were significant differences in plant height which reflects the effect of organic fertilizer on plant growth. Similarly, Onwudike *et al.* (2015)observed significantly ($P < 0.05$) higher plant height in maize treated with rice mill waste and poultry manure relative to control. Plant height is positively correlated with the productivity of plants (Saeed *et al.*, 2007).The poultry manure also had significant ($P<0.05$) differences in the leaf area and other parameters. The increase in leaf area had been claimed to be directly influenced by nitrogen supply in fertilizer applied (Ehigiator, 1990). Plants grown on the control plots produced the shortest plants as they depended on the native fertility of the soil which from the result of routine analysis was below the critical level (Ibude *et al.*, 1988).

According to Al-Farhad *et al.* (2009), herbage yield is a function of growing conditions and crop management practices. Herbage yield was significantly affected by the rates of poultry manure application. The higher yield could be probably due tohigher leaf area associated with poultry manure amended plots. Higher leaf area is associated with greater light interception leading to the production of higher assimilates which can be translocated to the entire plant (Jombo *et al.*, 2012) leading to higher yield. The optimal amaranth yields were obtained at 15 t/ha rate of poultry manure (Emede *et al.*, 2012).Application of poultry manure (Adediran and Banjoko,

2003) has positive correlation with the yield of crops. When rice husk waste was combined with NPK 15-15-15 to test the effect on maize crop in an acid ultisol of Owerri in Imo State, 10 t/ha + 300 kg/ha NPK gave a better stem girth, leaf area and grain yield (Nwosu and Chikere-Njoku, 2015).

Landis *et al.* (1990) opined that organic material with particles less than 0.1 mm in size (like sawdust) will hold some water, but this water will be unavailable to the plant and very little air is held in fine particle mixes and the over compacted media will hold too much water which will suffocates the roots. Therefore, the ideal mixes were the ones that had a balance between medium and coarse particles. This characteristics best fitted the mixtures (Ogbodo, 2012) that contained rice husk in which lettuce plants performed better and deduced that the better physical and chemical properties of the rice husk and poultry manure mix led to higher yield of lettuce in Ebonyi State.

2.6 Microbial population and species during composting process

Many factors, including number or species of micro-organisms, pH, moisture, aeration and the available nutrients in the composting material (Donahue *et. al.*, 1990) are identified as determinants to the rate of decomposition of organic materials.During composting process(Levanon and Pluda, 2002) reported that microorganisms transformed organic raw materials into compost by breaking them down to simple compounds and reforming them into new complex compounds. Bacteria, fungi and actinomycetes are responsible for the decomposition of organic materials. Among the microorganisms (Tan, 2014) bacteria maintain the most abundant species and metabolically active in the composting process. Schlegel (2003) reported that in the thermophilic phase of the composting process, bacteria from genus *Bacillus* dominate, while the temperature of 70 ^{0}C is regarded as the critical temperature of thermophilic bacteria development. Microorganisms can change the chemistry of organic wastes by converting essential plant nutrients from organic form into inorganic forms readily availablefor plants.

Microbial growth could utilize available nutrient for metabolic processes and energy release, therefore limiting the composting process. During aerobic composting there is a continual change in the microbial populationwhich according to Ali (2014) and Neher (2013), composting process is facilitated by microorganisms through community succession and abundance changes. Initially fungi and acid producing bacteria appear during the mesophilic stage but as the temperature increases above 40 ^{o}C, they are replaced by thermophilic bacteria, actinomycetes and thermophilic fungi. Lopez-Gonzalez (2015) reported that at the thermophilic stage, composting materials are mainly dominated by thermophilic microorganisms to degrade recalcitrant materials. At temperatures above 70 ^{o}C these are followed by spore-forming bacteria as confirmed byNeher (2013) who reported that bacteria are very important microbial populations that exist throughout the composting period and Berquist *et al.* (1999) earlier reported thatat higher temperature exceeding 70 ^{o}C, *Caldibacillus cellulvoraus* responsible for the decomposition of cellulose is dominant in the compost. An inhibiting effect of high temperature obtained in the thermophilic phase in relation to pathogenic bacteria in the compost was reported by Hassen *et al.* (2001).

Finally, as the temperature falls, the mesophilic bacteria and fungi appear again as observed by Wieland and Sawicka (2009)who reported that with the temperature drop below 40 ^{o}C, the number of fungi in the composted mass increased. Studies of Wolna-

Maruwka *et al.* (2009) indicated that increase of temperature in the composted materials led to a drop in the proliferation of fungi and also reported that a successive factor resulting in the decrease of fungi number could be the increase of pH in the composted materials. The mesophilic stage is short and the primary role of the mesophilic bacteria is to raise the environmental temperature for the thermophilic microorganisms that follows. The mesophilic bacteria utilize the most readily accessible carbohydrates and decomposable proteins while the thermophilic bacteria decompose the protein and non-cellulose carbohydrate components in compost. They also attack the lipid and hemicellulose fractions, but cellulose and lignin appear to resist their activity. Thermophilic actinomycetes can grow at higher temperatures than thermophilic fungi hence the actinomycetes are abundant at the highest temperature phase of composting.

Macro-organisms are also found in compost piles and they are considered to be the physical decomposers due to their grinding, biting, sucking, tearing and chewing behaviour which further reduces the materials into smaller pieces. However, aerobic bacteria are the most important decomposers and are very abundant. The organisms utilize carbon as energy source to keep on eating and nitrogen to build up protein in their body cells to grow and reproduce. They obtain energy by oxidation process which eventually heats up the compost pile from ambient temperature. Studies of Tiquia *et al.* (2002) indicated that the greatest metabolic activity in the compost heap occurred in temperatures ranging from 25 – 45 ^{o}C. For a successful composting process, aeration, moisture, temperature and acidity should be maintained within favourable range. *Actinomycetes* are also active decomposers capable of decomposing the more resistant organic materials such as lignin, cellulose, starches, and proteins in composts. Fungi are also responsible for organic matter decay in compost pile.These microorganisms (Wolna-Maruwka *et al.*, 2009), besides further organic matter decomposition, produces antibiotic substances serving for natural disinfection of the composts.

2.7 Fertility status of soils derived from coastal plain sands

Acid tropical soils with a pH lower than 5.5 covered over 25%of potentially arable land in Nigeria (Ayeni and Adeleye, 2011). These soils which occupy more than 27000 km^2 of agricultural lands in the southern part of Nigeria (Chude *et al.*, 2005), are characterized by low cation exchange capacity, low base saturation, high concentration of exchangeable Al^{3+} and poor in fertility.The soil pH is generally acidicas a result of low buffering capacity hence basic cations such as Ca, Mg and K are usually leached out leaving acidic elements (H, Al and Mn) on the exchange site. Al^{3+} ion is not only toxic (Agbede *et al.*, 2015) but also reduces the availability of important nutrients such as phosphorus and magnesium. This level of acidity could be attributed to the high amount of rainfall prevalent in the region which is capable of leaching the basic cations beyond the root zone. Such condition can reduce microbial fixation of atmospheric nitrogen (Gbadegesin *et al.*, 2011).However, liming and application of organic fertilizers are recommended (Agbede *et al.*, 2015) to reduce the acidity for sustainable crop production.

Acid sands soils are found in seven states in Nigeria, viz; Anambra, Imo, Abia, Cross River, Edo, Delta and Akwa Ibom states. As earlier reported by Enwezor *et. al.* (1981) that 'acid sands' soils of southern Nigeria were low in CEC, low base saturation and low fertility level, leading to various nutrient deficiencies. They added that pH (H_2O), organic carbon and total nitrogen in soils of Akwa Ibom state were 4.7, 1.03% and 0.09%, respectively. Ca, Mg, K and percent base saturation were recorded to be 1.50, 0.50, 0.07 cmolkg^{-1} soil and 22.6%, respectively. The soil is formed from sandstones and is characterized by low nutrient reserves (Enwezor *et. al*., 1981). The fertility status of the soil at the study site was reported by Ekong and Uduak (2015) to be low with pH (5.2 - 5.4) and high in organic matter content with mean value of 4.68%. Total N and available P were low (0.10 – 0.12% and 4.70 – 5.18 mgkg^{-1}) respectively.The exchangeable Ca (3.20 - 3.50 cmol/kg), Na (0.06 – 0.07cmol/kg),and K (0.03 - 0.15 cmol/kg)were low while Mg (1.40 – 1.60 cmol/kg)was high.The micronutrient contentsFe (169.14 – 177.40 mg/kg) > Zn (5.08 – 5.88mg/kg)> Mn (2.18 – 2.48 mg/kg) > Cu (1.30 – 1.70 mg/kg) > B (0.55 – 0.67 mg/kg)were high in that order. The soil requires the application of organic and inorganic fertilizers for sustainable crop production.

The soil fertility rating as reported byIbia (2005) described soils of Akwa Ibom State as inherently low in fertility, strongly weathered, acidic in reaction and fragile in nature. Chemical properties of soils derived from coastal plain sands (Ibia, 2005) was given as pH (4.0 – 6.10), CEC (1.05 – 18.70 cmol/kg), average organic matter content (3.11%), total nitrogen (0.03 – 0.23%), available P (10.0 – 196.7 mg/kg) which were high and exchangeable K (0.02 – 0.44 cmol/kg). The acidic nature of the soil is linked to excessive leaching of the basic cations by torrential rainfall leaving behind the acidic cations in the soil. The acidic condition of the soil can lead to phosphate fixation and low level of nitrogen fixation by soil microorganisms.

The critical value of total nitrogen in tropical soils was reported to be 0.15% (FMANR, 1999). The low level of total nitrogen in the soil is attributed to leaching of nitrates by excessive rainfall and plant uptake which has serious implications on the fertility of the soil. Landon (1991) gave the critical limits of K (0.2 cmol/kg), Ca (4.0 cmol/kg) and Mg (1.5 cmol/kg) in soils of the southeast region of Nigeria. The critical limits of phosphorus, exchangeable calcium and magnesium in tropical soils (Esu, 1991) were reported as 10 - 20 mg/kg, 2 - 5 cmol/kg and 0.30 – 1.0 cmol/kg, respectively.The critical valueforexchangeable potassium and sodium (Chude *et al.*, 2011) was reported to be0.20 cmol/kg.

However,Ibude *et al.* (1988) earlier gave the critical level of some chemical properties in the acid sand soils of the southeast Nigeria to be organic carbon (11.60 gkg^{-1}), total N (1.50 gkg^{-1}), available P (8.5 $mgkg^{-1}$), Ca (1.5 $cmolkg^{-1}$), Mg (0.28 $cmolkg^{-1}$) and K (0.16 $cmolkg^{-1}$). Ibia (2012) reported on the critical value of micronutrients as Mn (1.0 mg/kg), Cu (0.2 mg/kg), Zn (0.5 mg/kg) and Fe (4.5 mg/kg). The contents ofmicronutrients in soil of the study area were high and it could be attributed to the nature of the metal ions with strong electrical charge (+2) which makes them attracted to the cation exchange sites of clay and organic matter, accumulating in the soil surface. However, the metallic micronutrients usually form complex with other elements to enhance their availability and they are adequately supplied by organic manures. Micronutrients are essential elements for crop production and food quality and they are released through the biological degradation of organic materials by soil microorganisms (Erhart and Hartl, 2010).

2.8 Effects of compost on soil properties

Most agricultural soils in the southeast region of Nigeria were reported to be impoverished due to high weathering of the soils, leaching and intensive cultivation (Akanbi and Togun, 2002) and these problems necessitate the application of soil amendment in form of compost to augment the fertility of the soil for sustainable crop production. Compost does not only act as a source of nutrients to the soil but it also improves soil characteristics.Composts are widely used as a soil amendment to improve soil structure, provide plant nutrients and facilitate the re-vegetation of disturbed soils (Sarwar, 2005; Kayode *et al.*, 2013). Organic fertilizer (Agbede *et al.*, 2015) was reported to improve the availability of essential nutrients in deficient soils and its base elements content capable of reducing soil acidity.

2.8.1 Physical Properties

Compost provides a more stabilized form of organic matter than raw wastes and improves the physical properties of soil such as water holding capacity, bulk density, aeration, hydraulic conductivity, soil aggregation and resistance of soil to water and wind erosion (Aggelides and Londra, 2000). Compost enhanced aggregation and stability of the soil therefore improving the structure and porosity of thesoil. Organic matter affects soil aggregation due the actions of gummy compounds, polysaccharides and fulvic acid that bind the soil particles together. Hanay *et al.* (2004) reported that aggregate stability of a clay loam soil increased by 16 and 33%, while water holding capacity increased by 2.3 and 5.7% by the application of 10 and 15 t/hacompost due to improved pore size distribution. Aggregate stability prevents clogging and reduces erosion, improves water infiltration and water holding capacity (Martinez-Blanco *et. al.*, 2013).

It was earlier reported by Gallaher and McSorley (1994) that compost treatment increased water storage by an amount equivalent to 12.5 cm when rainfall or irrigation was used on corn crop. Rong *et al.* (2001) reported a decreased soil bulk density and increased soil moisture when they conducted a plot trial on the effects of combined inorganic and organic fertilizer application on red upland soil.The incorporation of compost into compacted soils decreased the bulk density due to increasein volume of macro pores, better aggregation and mixing of soil with less dense organic material. Similarly, Ijiyokun *et al.* (2014) reported a decrease in soil bulk density when 10 t/ha of compost was applied to soil in Abeokuta and the reduction was 1.02 g/cm^3 relative to control (1.21 g/cm^3).

Wapa *et al.* (2013) reported that application of different sources of organic manures had significant changes in the individual particle size distribution but not on the textural class of the soil. They stated that the percentage sand significantly ($P<0.05$) decreased by the addition of cow dung as compared with sheep/goat and poultry droppings. Onwudike *et al.* (2015) reported that application of sawdust, rice mill waste and poultry manure compost did not change the texture of the soil when compared to the control. Brady and Weil (2002) reported that management practices generally do not alter the textural class of the soil in the field scale and that the texture of a soil can only be changed by mixing it with another soil of a different textural class.

Organic amendments (Ojeniyi and Adejobi, 2012) have been found as an easy way of improving the soil physical properties as well as enhance natural soil nutrient re-build and soil quality protection. Liu *et al.* (2009) observed that manure application

increases soil aggregation which in tum increases soil aeration, water infiltration and biodiversity.Obi (1959) and Stephens (1961) in their earlier report recommended the use of compost for the following reasons: slow release of balanced nutrients reserved during decomposition,improvement of the physical properties of the soil which include: soil structure, protection of the soil from structural damages by rain, soil temperature regulationand reduction of run-off and erosion. It also involves improvement of aeration, infiltration rate, permeability and aggregation.

2.8.2 Chemical Properties

Various authors have reported that application of organic materials influenced the chemical properties of soil. Ogbodo (2012) observed that soils amended with rice husk mixed with poultry manure had the highest pH value compared to other treatments on the post- trial soil propertiesand concluded that mixing rice husk and sawdust with organic amendment improved the media pH, organic matter, available P, total nitrogen, cation exchange capacity, exchangeable calcium, potassium and sodium. The change in the pH values of mineral soils by compost application depends upon the composted materials, initial pH and buffering capacity of the soil. Organic amendments can increase the pH of acidic soils (Whalen *et al.*, 2000) thereby improving availability of macronutrients while reducing the solubility of Al^{3+} and Mn^{2+} ions.Orhue *et al.* (2014) reported that the pH of soils treated with abattoir effluent increased and tended towards neutrality.

Soil pH was maintained near the original soil pH level when N-based compost manure was applied (Eghball, 2002). However, Wapa *et al.* (2013) reported a significant decrease in pH from 6.66 to 5.88 with application of poultry droppings in

Sudano-Sahelian Savanna ecological zone. Some scientists have reported slight increase in soil pH when compost manure was applied.Nwosu and Chikere-Njoku (2015) reported that application of rice husk waste combined with NPK at the rate of 10 t/ha RHW + 300 kg/ha NPK significantly improved the buffering potentials on an acid ultisol of Owerri. Compost application significantly increased soil pH and the contents of N, P, K, Ca, Mg and Na in the topsoil (Haute, 2014).AdeOluwa and Bello (2017) also reported that Ibadan brewery based grade A compost and Ibadan brewery based grade B compost influenced the post-harvest soil properties significantly ($P<0.05$) with a better pH (6.7 - 6.8), organic carbon (3.1 – 3.2 g/kg), N (0.2 - 0.3 g/kg), available P (15 – 21 mg/kg), Ca (4.1 – 5.8 cmol/kg), K (0.3 cmol/kg), Na (0.3 – 0.8 cmol/kg), Mn (752 – 777 mg/kg), Fe (78 – 99 mg/kg) and Cu (11 – 16 mg/kg) with mean edible fresh weight in grade A compost (13.37 t/ha) and grade B compost (10.94 t/ha) yields of *Amaranthuscaudatus*. Compost treatments had positive influence on the inherent properties of the soil as confirmed by Oladipo, *et al.*(2005) that organic wastes contain essential nutrients needed for improvement of soil fertility, plant growth and yield.

Brady and Weil (2002) reported that finished compost is generally more concentrated in nutrients than the initial combination of raw materials used. Compost is a source of plant nutrients such as N, P, S and K and can enhance CEC, reduce Al toxicity and P-fixation in strongly acid soils. Significant increase of organic C with the application of compost as compared to the inorganic fertilizers was reported by Diacono and Montemurro (2010). Compost improves the availability of plant nutrients and increases soil biota (Vanlauwe *et. al.,* 2010). Increased cation exchange capacity in response to compost applications improved nutrient retention in soil (Preusch *et al.*, 2002). Research findings indicated that application of compost at 15 to 30 t/ha increased the CEC of most mineral soil by a minimum of 10 % (McConnell *et al.*, 1993). Deli (2011) observed that the CEC was significantly increased by the application of cow dung while poultry droppings and sheep/goat manure showed no significant increase. Compost improves the chemical properties of the soil by supplying essential nutrients through cation exchange process.It was reported that the soil electrical conductivity significantly increased (0.039 dSm^{-1}) with the application of sheep/goat manure while cow dung and poultry droppings did not show significant effect (Wapa *et al.*, 2013).

Soils treated with organic manures had significant higher values of organic carbon. Akinyeye *et al.* (2012) observed increase in organic carbon content on contaminated soil at Ikpobain Benin City with application of abattoir effluent. There was significant increase in the total nitrogen content of soil with application of poultry droppings (Deli, 2011). The high content of nitrogen in poultry manure originates from its content of uric acid which is rapidly converted to ammonium (NH_4). Nitrogen and phosphorus contents were increased in soils treated with abattoir effluent (Osemwota, 2010). Manure application in excess of crop requirements can cause a significant build-up of P and N in soil. Orhue *et al.* (2014) reported that K, Mg, Ca and Na as well as micronutrients such as Fe, Cu and Zn significantly increased in abattoir effluent treated soil compared to the control. Awotundun *et al.* (2005) observed that application of animal dung and poultry droppings increased availability of phosphorus in the soil solution and reduced phosphate adsorption. Eghball (2003) reported that application of nitrogen based compost increased soil P levels which contributed to crop P uptake for up to 10 years without additional P application. Conclusively, compost application (Ahmad*et al*., 2008) enhanced availability of plant nutrients and plant growth and (Akanni and Ojeniyi, 2007; Ayeni and Adeleye, 2011) reported that agro-wastes has improved soil physical and chemical properties and yield of tropical crops.

2.8.3 Biological Properties

Compost is a source of carbonand energy for microbial growth.An increase in soil organic matter content through compost applicationaccelerates the activity of soil microorganisms which play an important role in decomposition of organic materials and solubilisation of certain nutrients. Amujoyegbe *et al.* (2007)reported that microorganisms from the soil decay the organic fertilizer to make its nutrients available for plant uptake. Compost application does not only add millions of microbes to the soil but they are also stimulated by the fresh supply of organic matter in the compost. Organic fertilizer enhances soil biological activity and the colonization of mycorrhizae that enhances mutuality association between fungi and higher plants (Karlen *et al.*, 2008).Significant increase in soil organic carbon with increasing rates of manure was reported by Eneji and Uzoukwu (2012).Other studies (Okpara and Mbagwu, 2003; Iren *et al.*, 2011) have shown that organic fertilizer increases soil organic carbon content more than inorganic fertilizers. Adrien (2006) reported that application of organic manures significantly increase levels of organic C and N in the soil.

Organic fertilizers are alternative means of increasing soil fertility, increasing the soil organic matter content, support the growth of microorganisms and could serve as control against soil pathogenic microorganisms (Olayinka, 2009; Ndubuisi-Nnaji *et* *al.*, 2011).The application of compost to soil can also supply essential microbes as biological control agents for the suppression of soil-borne diseases (Egwunatum and Lane, 2009). One of the important roles of organic manure in the soil is the control of nematodes (Adekunle, 2008). Moreover, Ediene *et al.* (2013) reported on the bacterial and fungal species isolated on palm oil mill effluent (POME) treated soil to be (*Clostridium butyrium* and *Enterococcus gallinarium)* and*(Aspergillus niger, penicillium spp, Trichoderma spp* and *Mucor spp*), respectively. They suffice that microorganisms are good solubilizing agent of phosphorus that might have been responsible for the high values of P observed in the POME dump sites. Application of animal manure (cow dung and poultry litter) resulted in 45.28% improved biomass C, 66.48% improved soil microbial biomass N and 55.11% improved soil microbial biomass P over inorganic-only treated plots. The treatment also resulted in enhanced enzymatic activities of dehydrogenase, β-glucosidase, acid phosphatase and protease (Eche *et al.*, 2015).

2.8.4 Biochemical properties

During decomposition, microorganisms assimilate complex organic substances and release inorganic nutrients. An adequate composting process kills pathogens and stabilizes compost organic carbon before material is applied to the soil (Erickson *et al.*, 2009). One method to improve soil quality involves the addition of several kinds of composts made from solid organic waste, sewage sludge, green and industrial wastes, or animal manure (Masciandaro *et al.*, 2000; Cox *et al.*, 2001; Madrid *et al.*, 2007). Compost is considered to be environmentally safe, agronomically advantageous, and a relatively cheapsoil organic amendment (Hepperly *et al.*, 2009).

There is considerable interest in soil enzyme activities as indicators of changes following soil treatment effects such as the incorporation of organic materials. Studies of (Bhattacharyya *et al.*, 2001; Saviozzi *et al.*, 2002) indicated that addition of compost to the soilinfluenced enzymatic activities because the added organic fraction contains intra- and extra-cellular enzymes and could also stimulate the growth of soil microbiota in response to the presence of easily available carbon. Saviozzi *et al.* (2002) reported a significant increase of dehydrogenaseby compost amendments on soils with low organic matter content. Okolo *et al.*(2007) reported that with increased doses of compost applied to soil, phenolic compounds in soil increase but did not reached the level that disturb soil, plant health or growth.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The field trials of the compost treatmentswere conducted at the Teaching and Research Farm of Akwa Ibom State University, Obio Akpa Campus, Akwa Ibom State in Southeast Nigeria on the performance of *Amaranthus cruentus* (Linn). The Farmis located between latitudes 4° 30′ N and 5° 30′ N and longitudes 7° 30′ E and 8° 00′ E of the Greenwich Meridian (SLUS-AK, 1989).Composting of rice husk/battery cage waste (RH/BCW) and sawdust/battery cage waste (SD/BCW) were carried out in Efiat Offot in Uyo metropolis.

3.1.1 Climate

The site is in the humid tropical region with a long raining season from April to October.The monsoon air mass blowing over the Atlantic Ocean sweeps through this zone resulting in heavy annual rainfall that ranged from 2000to 2500 mm in the wet season. The annual temperature rangedfrom 24to 30 °C and annual relative humidity ranged from75to79% (AKSU MET, 2016).

3.1.2 Geology

The soil of this area was reported toform from the coastal plain sands parent material andclassified as an Ultisols based on USDA system of classification(SLUS-AK, 1989).The soil was rated as well drained, moderately low to medium in moisture holding capacity, with slightly acidic to strongly acidic reaction, medium in organic matter content and low in fertility(Soil Survey Staff, 1999).

3.1.3 Land use/Vegetation

The study area was originally tropical rainforest but now predominantly secondary forest due to intensive land use. The farming system in the area is rotational bush fallow with maize, cassava and pumpkin as the major crops grown solely or mixed. Mechanical tillage is the common method of land preparation. Chemical fertilizer is frequently used and the land has been cultivated with various arable crops for the past forty years by the defunct Research Institute, Polytechnic and College of Agriculture as well as the villagers and the present Akwa Ibom State University.

3.2 Organic materials used for composting

The organic materials used for the preparation of the composts were rice husk, poultry manure and sawdust (Plate 1). Rice husk was obtained from rice mill in Ini local government area and poultry manure was procured from a battery cage system under laying birds from the poultry unit of Victory Livestock Farm at Mbiet Ebe in Ibesikpo Asutanlocal government area whilesawdust from soft wood (*Gmelina arborea*) was collected from Itam timber marketin Itu local government area all in Akwa Ibom State.

The rice husk and sawdust were separatedinto three particle sizes (0.5, 1.0 and 2.0 mm).Samples of rice husk, poultry manure and sawdust weretaken to the laboratory to determinethechemical properties, moisture and dry matter contents. The carbon to nitrogen (C/N) ratios of the materials was used for the determination of composting ratios.

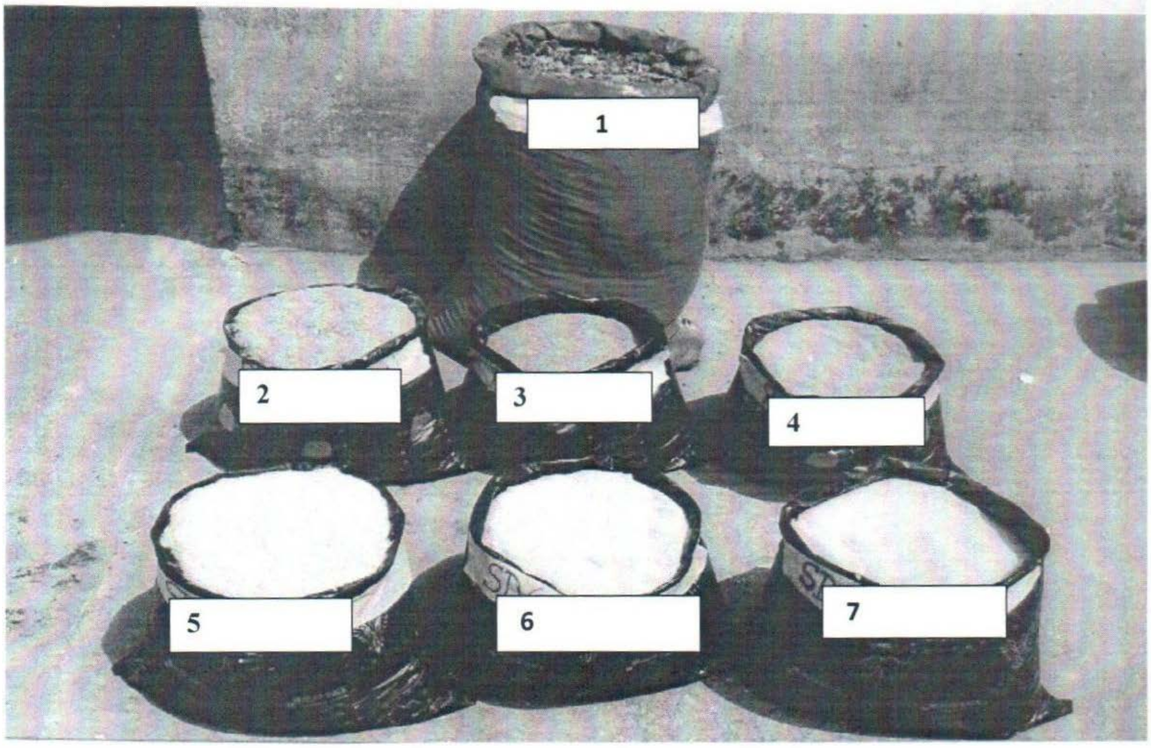


PLATE 1: Samples of composting materials

Key:

1. Poultry manure from battery cage system (BCW)
2. 2.0 mm particle size of rice husk (RH)
3. 1.0 mm particle size of rice husk (RH)
4. 0.5 mm particle size of rice husk (RH)
5. 2.0 mm particle size of sawdust (SD)
6. 1.0 mm particle size of sawdust (SD)
7. 0.5 mm particle size of sawdust (SD)

3.2.1 Determination of the particle sizes of rice husk and sawdust

Rice husk and sawdust were subjected to particle size separation using sieve method.

Procedure of particle size separation

The grain size characteristics of organic materials that are predominantly coarse grained are evaluated by a sieve analysis. A nest of sieve was prepared by stacking test sieves one above the other with the largest opening (2.0 mm) at the top followed by sieves of successively smaller openings (1.0 and 0.5 mm) and a catch pan at the bottom. Samples of rice husk and sawdust were poured into the top sieve with the nest covered, and then shaken by hand until each particle dropped to a sieve with openings too small for large particles to pass through. Particles retained in the catch pan were separated into 0.5, 1.0 and 2.0 mm particle sized materials, respectively. The cumulative weight of all materials larger than each sieve size was determined and divided by the total sample weight to obtain the percentage retained for that sieve size.This value was subtracted from 100%, to obtain the percentage passing that sieve size. One (1) kg of rice husk and sawdust was sieved at each round. Sieving was interrupted after 10 minutes to remove blockage of the sieve apertures.

Test procedure

1. The weight of each sieve as well as the bottom pan used in the analysis was recorded
2. The weight of each dry sample was recorded.
3. All the sieves were clean and assembled in the ascending order of sieve numbers.
4. The sieveswerehand-shaken for 10 minutes.
5. The sieves plus the weight of retained samples were carefully weighed.

6. Weight of the bottom pan with its retained fine sample was also taken.

Data Analysis

1. The mass of sample retained on each sieve was obtained by subtracting the weight of the empty sieve from the mass of the sieve + retained sample.
2. The percent of particles retained on each sieve size was calculated and dividedby the weight of the original sample mass.
3. The percent of particles passing the sieve size with finer opening was calculated and subtracted from 100% on each sieve as a cumulative procedure (Krishna, 2010).

3.2.2 Composting process

The C/N ratios of rice husk, sawdust and poultry manure were used to determine the ratios of RH, SD and BCW in the composting process. The composts were made up of twenty four piles. Rice husk (RH) with 0.5, 1.0 and 2.0 mm particle sizes were composted with battery cage waste (BCW) in 1:1, 1:4, 1:8 and 1:16 ratios at each level of particle size using wet weight basis, giving a total of twelve compost treatments.Also, sawdust (SD) with 0.5, 1.0 and 2.0 mm particle sizes were composted with battery cage waste (BCW) in the same ratios (1:1, 1:4, 1:8 and 1:16) at each level of particle size using wet weight basis, giving a total of twelve compost treatments and a grand total of twenty four compost treatments. The twenty four compost treatments were: SD/BCW (1:1) 0.5 mm, SD/BCW (1:1) 1.0 mm, SD/BCW (1:1) 2.0 mm, RH/BCW (1:1) 0.5 mm, RH/BCW (1:1) 1.0 mm, RH/BCW (1:1) 2.0 mm, SD/BCW (1:4) 0.5 mm, SD/BCW (1:4) 1.0 mm, SD/BCW (1:4) 2.0 mm, RH/BCW (1:4) 0.5 mm, RH/BCW (1:4) 1.0 mm, RH/BCW (1:4) 2.0 mm, SD/BCW

(1:8) 0.5 mm, SD/BCW (1:8) 1.0 mm, SD/BCW (1:8) 2.0 mm, RH/BCW (1:8) 0.5 mm, RH/BCW (1:8) 1.0 mm, RH/BCW (1:8) 2.0 mm, SD/BCW (1:16) 0.5 mm, SD/BCW (1:16) 1.0 mm, SD/BCW (1:16) 2.0 mm, RH/BCW (1:16) 0.5 mm, RH/BCW (1:16) 1.0 mm and RH/BCW (1:16) 2.0 mm.

These compost treatments were kept in windrows or heaps under zinc roof shades. Turning of compost heaps and sprinkling of water were carried out at three days interval for the first two (2) weeks and once a week for the next one month and forth-nightly for the remaining six (6) weeks of composting. Ambient temperature was taken before the compost temperatures were measured with the aid of a soil thermometer before and after each turning. The initial weight of each compost heap was takenat the commencement of composting and at four and eight weeks after composting.

3.2.3 Field Preparation/Nursery Operation

The experimental site was cleared manually and the residues packed. Four blocks were measured out and each block contained twenty four (24) experimental plots and the control. In all there were a total of one hundred (100) experimental plots. Vegetable beds measuring 1.5 x 1.5 m were marked out and constructed with 1.0 m paths in between blocks and 0.5 m between plots. The seeds of *Amaranthuscruentus*were procured from Research Institute, Umudike in Abia State. The nursery was established in the field and the nursery bed was prepared beside the experimental plots. Poultry manure was incorporated, watered and allowed in the nursery bed for two days before the seeds were sown by broadcasting. Thereafter, watering of the nursery bed was done regularly and seedlings started to emerge 7 days after sowing. The nursery bed was protected with net to prevent attack of seedlings by insects. Adequate watering was done 30 minutes before the time the seedlings were uprooted. The seedlings were removed with ball of soil to avoid transplanting shock.

3.3 Field experiment

The composts produced were tested on the performance of *Amaranthus cruentus* in field experimentsin 2016 for the first growing season which was in the dry season andin 2017 for the second growing season which was in the rainy season.Twenty five raised beds per block or replicate and twenty five flat beds per blockwere used in the experiments in 2016and 2017 seasons, respectively. Twenty (20) ton/ha of the different compost treatments was applied by broadcasting in the respective plots and incorporated into the soil. Each experimental plot measured 1.5 x 1.5 m and received 4.5 kg of the compost. The composts were broadcasted and incorporated into surface of the beds two weeks before transplanting of seedlings to encourage rapid mineralization of the composts and to allow for equilibration.

Planting holes were dibbled with sharp pointed stick and the seedlings were carefully and firmly inserted into the hole made for them. The seedlings were transplanted at two (2) weeks after sowing at average height of 2 cm, stem girth of 0.3 cm and leaf area of 1.4 cm^2in 2016 and 2017 seasonsThe experimental plots were moistened before the transplanting of seedlings on them took place. This was done to enable the escape of carbon dioxide from the soil to prevent burning and scorching on the tender seedlings mostly during the 2016 cropping season that fell in the dry season. Two seedlings were transplanted to each stand and later thinned to one plant per stand after two weeks of transplanting.The seedlings were spaced at 30 x 30 cm and planted at the depth of 3cm. Seedlings were supplied to missing stands a week after transplanting. The experimental field was kept weed free till harvestby regular hand pulling of weeds on the beds while hoe was used to weed between the beds and edges of experimental area to reduce weed competition for growth, and create pest and disease free environment.

The plant height, stem girth and leaf area were measured using meter tape at4, 6 and 8 weeks after transplanting (WAT). Plant height was measured using meter tape from the surface of the soil to the tip of the tallest leaf. The stem girth was measured by winding thread on the stem near the ground level and then measuring it out with the meter tape while the leaf area was measured by the length and breadth of the leaf and multiplying the product by a factor of 0.65 (Nwafor *et al.*, 2010). Five plants per plot were randomly selected from the inner rows for the determination of growth parameters. The same number of plants were used to determine the fresh leaf yield in (ton/ha).

3.4 Laboratory studies

3.4.1 Laboratory analyses of experimental soil and composting materials

Soil samples for this experiment were collected from the Teaching and Research Farm of Akwa Ibom State University, Obio Akpa Campus. Random sampling method was used in collecting soil samples at the depth of 0 –15cm and 15 – 30 cm using soil auger for routine analysis.Fresh samples of the three particle sizes of rice husk and sawdust as well as the poultry manure meant for composting were collected for laboratory analysis

The soil samples were ground using agate mortar and pestle and sieved to obtain particles < 2 mm and were stored in airtight container for the determination of some physical and chemical properties.Fresh samples ofthe organic materials were collected, air-dried and stored for the determination of chemical properties and moisture contents. Compost samples were collected at 4 and 8 weeks after composting (WAC) forthe determination of chemical properties.The compost samples were ground using agate mortar and pestle and sieved to obtain particles < 2 mm for the determination of some chemical properties. The dry compost samples were also collected at 8 WAC for microbial analyses.The chemical properties and moisture contents of rice husk, sawdust and battery cage waste were determined before composting and at four and eight weeks after composting. Soil and compost pH, electrical conductivity, particle size analysis, organic carbon, total nitrogen, available phosphorus, exchangeable cations and micro-nutrients were determined in the laboratory.

3.4.1.1 Moisture content

Ten (10) grams of the organic materials were weighed into moisture can to obtain the first weight (A). The samples were oven-dried for 8 hours to constant weight at 105°C. The oven-dried samples were removed from the oven and reweighed to obtain the second weight (B). Percentage moisture content was calculated as: A – B/ B – weight of moisturecan x 100 (Richard *et al.,* 2002).

3.4.1.2 Soil and compost pH

Soil pH was determined in 1:2.5 soil-water ratio and that of the compost determined in 1:4 compost-water ratio using electrode pH meter (Bates, 1954).

3.4.1.3 Electrical Conductivity (EC)

Electrical conductivity was determined using a conductivity bridge by dipping the electrode into the 1:2.5 soil-water and 1:4 compost-water suspensions (Hanna, 1964).

3.4.1.4 Particle size analysis

Particle size distribution of the soil sample was determined by hydrometer method using sodium hexametaphosphate (calgon) as a dispersing agent (IITA, 1979).

3.4.1.5 Organic Carbon

Organic carbon was determined by wet oxidation method of Walkley-Black as outlined by Nelson and Sommers (1982). Percentage organic matter was obtained by multiplying the value of organic carbon by a factor of 1.724.

3.4.1.6 Total Nitrogen

This was determined by regular macro-kjeldahl method using 0.5 mm mesh sample as described by Bremner(1996).

3.4.1.7 Available Phosphorus

This was extracted by the Bray 1 method (Bray and Kurtz, 1945) and P in solution determined colorimetrically by the ascorbic acid molybdate blue method (Murphy and Riley, 1962).

3.4.1.8 Exchangeable Cations

Exchangeable cations (K, Mg, Ca and Na) were extracted using 1N NH_4OAC (Sparks, 1996) at pH 7. The sodium and potassium were determined by a flame photometer while calcium and magnesium were read from Atomic Absorption Spectrophotometer (Model 939).

3.4.1.9 Micro-nutrients

Micro-nutrients (Fe, Cu, Mn and Zn) were extracted with double acid (HCl and H_2SO_4) and their concentrations read from AAS (Baker and Amacher, 1982).

3.4.1.10Microbial Analyses

The microbial bacteria, actinomycetes and fungi population in the composts were analysed followingstandard laboratory procedures. Dilution method for plating and microbial population count was carried out by the method of Zuberer (1994). It involved the use of nutrient agar (International Diagnostic Group) modified with 0.05 g/litre of *Nystatin* incorporation to prevent the growth of fungi. Plating was done in triplicates for each dilution by the pour plate technique. Inoculated plates were inverted and incubated for 3 to 7 days. The number of mesophilic bacteria was determined on simple nutritive agar by incubation of plates at 26 ^{0}C for 48 hours (Kanska *et al.*, 2001). Thermophilic bacteria were determined on 3 % nutritive agar (Kanska *et al.*, 2001) and the plates were incubated for 24 hours at 55 ^{0}C. The number of actinomycetes was determined on pachon's selective medium (Kanska *et al.*, 2001) by incubation of plates for 7 days at 26 ^{0}C. Fungi were cultured with malt extract, incubated for 5 days at 24 ^{0}C and observed under X100 objective lens as described by Demis (1994). The colonies were counted using colony counter while characterization and identification of isolates were done based on gram stain, motility test, catalase, coagulase, indole, oxidase and citrate oxidation and fermentation tests (Gadd *et al.*, 2007).

3.4.1.11 Plant Tissue Analyses

At the end of the experiment, two plants per plot were uprooted, the fresh weight of the shoot and the root were taken in each case and oven- dried at 105 °C for 48 hours. The oven-dried samples were milled into powder using a laboratory blender and were chemically analysed. Two (2) grams of the ground samples were digested with 30 ml of HNO_3 and 5 ml each of $HClO_4$ and H_2SO_4 to extract P, K, Ca, Mg, Cu, Zn, Mn and Fe.Total nitrogen content in the sample was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus was determined by vanadomolybdate method, K and Na by flame photometer while Ca and Mg were determined by the EDTA titration method (Faithful, 2002). The concentrations of the micronutrients (Cu, Zn, Mn and Fe) were read using AAS (Anderson and Ingram, 1993).

3.5 Data and statistical analysis

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replicates. Data collected before and during the composting process, the growth parameters, yield, nutrient contents in *Amaranthus cruentus* as well asthe post-trial soil analysis were subjected to analysis of variance (ANOVA) and means that showed significant differences were separated using Duncan Multiple Range Test (Duncan, 1995).

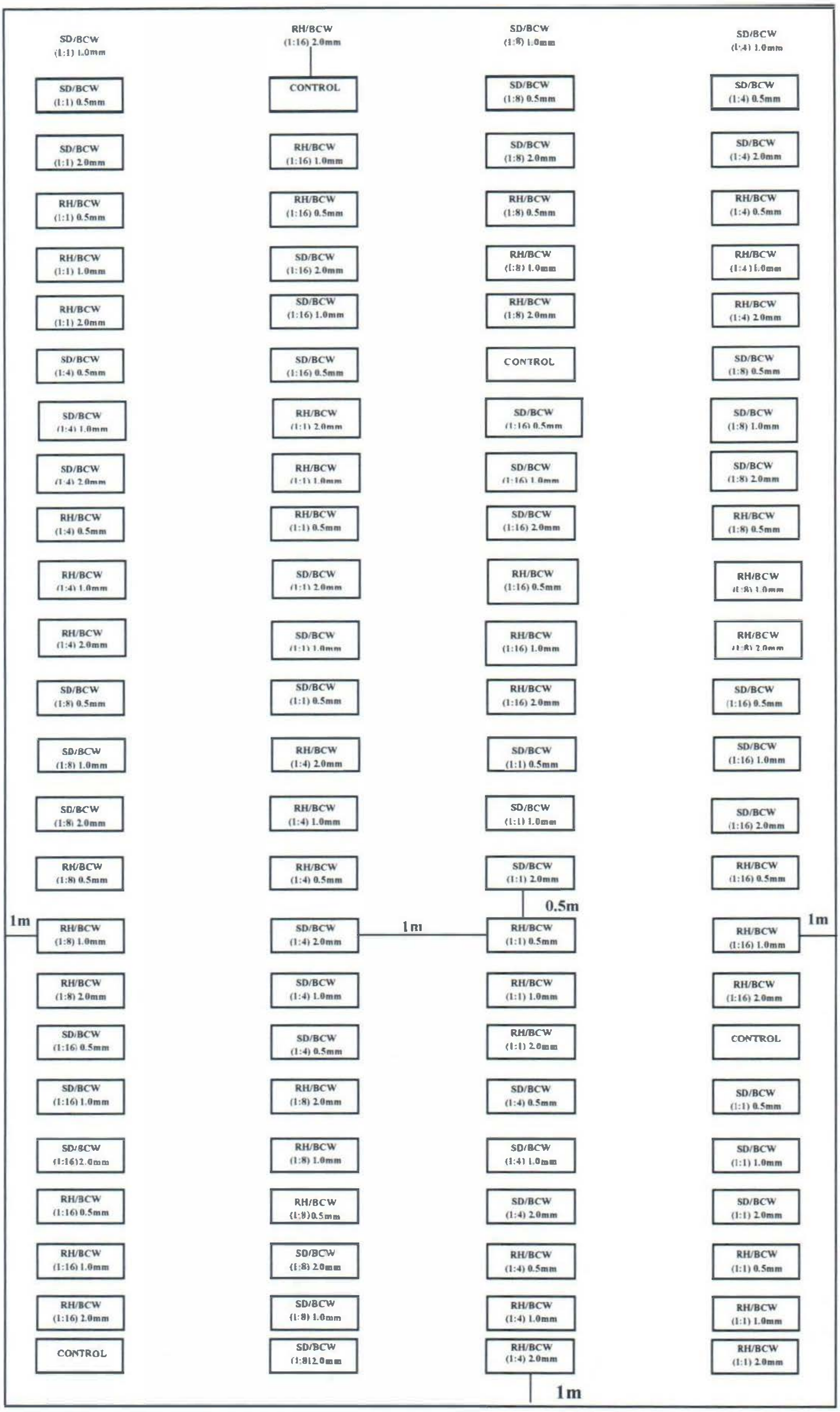


FIG. 1: Experimental Layout

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Particle sizes and moisture contents of fresh rice husk, sawdust and battery cage waste used in the composting process.

Analytical results of threeparticle sizes and moisture contentsof fresh rice husk and sawdust as well as battery cage waste are presented in Table 1. The results indicated that rice husk (RH) with 0.5 mm particle size had moisture content of 1.0% with 99.0% dry matter.Rice husk with 1.0 mm particle size contained 0.86% moisture and 99.14% dry matter content.Rice husk with 2.0 mm particle size contained 0.76% moisture and 99.24% dry matter content.The moisture content of sawdust with0.5 mm particle size was 0.80% and 99.2% dry matter content.Sawdust(SD) with1.0 mm particle size contained 0.76% moisture and 99.24% dry matter content.Sawdust with 2.0 mm particle size had moisture content of 0.70% and dry matter content of 99.30%. Poultry manure (BCW) from battery cage system had the highest moisture content of 87.0% with dry matter content of 13.0%.

The moisture content of BCW (87.0%) was significantly ($P<0.05$) higher than the moisture content of RH (0.5 mm) particle size (1.0%).The moisture content of RH (0.5 mm) was not significantly different from contentsof RH (1.0 mm) particle size (0.86%) and SD (0.5 mm) particle size (0.80%).These moisture contents werenot significantly differentfrom the moisture content ofSD (2.0 mm) particle size(0.78%).The moisture content of SD (2.0 mm) was not also significantly different from themoisture contentsof SD (1.0 mm) particle size (0.76%) and RH (2.0 mm) particle size(0.76%).

TABLE 1

Particle sizes andnutrient contents of rice husk, sawdust and battery cage waste used in the composting process

Oranic material	pH	EC (dS/m)	Org. C (g/kg)	TN (g/kg)	C/N	Ca	Mg	Na (mg/kg)	K	P	M.C (%)
Rice Husk (RH)											
0.5mm	6.20d	0.09b	351.53a	22.40a	16:1d	2193.33c	435.0c	214.33b	3401.0b	160.40b	1.00b
1.0mm	6.30d	0.08c	224.20f	22.10a	10:1e	2188.33c	439.0c	219.33b	3475.67b	162.50b	0.86b
2.0mm	6.30d	0.06d	235.60e	22.30a	11:1e	2196.33c	432.67c	212.0b	3336.33b	160.27b	0.76b
Saw Dust (SD)											
0.5mm	7.43b	0.03f	322.90b	5.01d	66:1a	3650.0b	716.67b	89.77c	3236.67b	212.17a	0.80b
1.0mm	6.90c	0.03f	311.70c	5.67c	55:1b	3636.33b	720.67b	92.33c	3089.20b	204.27a	0.76b
2.0mm	6.37d	0.04e	247.30d	5.70c	43:1c	3566.67b	728.33b	92.27c	3182.33b	204.33a	0.78b
Battery Cage Waste (BCW)	9.93a	0.70a	168.53g	20.96b	8:1f	13637.0a	2736.0a	307.73a	4990.80a	67.07c	87.0a

Means with the same superscripts along the same column are not significantly different ($p < 0.05$), RH = rice husk, SD = sawdust, BCW = battery cage waste

4.2 Chemical properties of fresh rice husk, sawdust and battery cage wasteusedin the composting process.

The chemical properties of fresh rice husk (RH), sawdust (SD) and battery cage waste (BCW) used in the composting process are presented in Table 1.

The pH of fresh battery cage waste (BCW) (9.93) was significantly ($P<0.05$) higher than the pH value of sawdust (SD) with 0.5 mm particle size (7.43). These pH values were significantly ($P < 0.05$) higher than the value obtained in sawdust (SD) with 1.0 mm particle size (6.90).ThispH value wassignificantly ($P<0.05$) higher than the pH value of sawdust (SD) with 2.0 mm particle size (6.37) but thisvalue was not significantly ($P<0.05$) different from the pH value of rice husk (RH) 2.0 mm (6.30). The pH of RH with 2.0 mm particle size was not also significantly different from the pH valuesofrice husk (RH) 1.0 mm (6.30) and rice husk (RH) 0.5 mm (6.20).

The electrical conductivity (EC) of BCW (0.70dS/m) was significantly ($P<0.05$) higher than the EC value of RH with 0.5 mm particle size (0.09 dS/m).The EC value of RH (0.5 mm) was also significantly higher than the EC value of RH with 1.0 mm particle size (0.08dS/m). The EC values of BCW and RH with 0.5 and 1.0 mm particle sizes were higher than the EC value ofRH (2.0 mm) particle size (0.06 dS/m). The EC values of BCW and RH materials were significantly ($P < 0.05$) higher than the EC value of SD (2.0 mm) particle size (0.04dS/m).The EC value of SD (2.0 mm) was higher than the value of SD (1.0 mm) particle size (0.03 dS/m). But the EC value of SD (1.0 mm) particle size was not significantly different from the EC value ofSD(0.5 mm) particle size (0.03dS/m).

The Organic carbon content of RH (0.5 mm) particle size (351.53g/kg) was significantly (P<0.05) higher than the content of SD (0.5 mm) particle size (322.90 g/kg).These values were significantly higher than the organic carbon content of SD (1.0 mm) particle size (311.70g/kg). They were also significantly (P <0.05) higher than the content of SD (2.0 mm) particle size (247.30g/kg).The organic carbon content of SD (2.0 mm) was higher than the content of RH (2.0 mm) particle size (235.60g/kg). They were also significantly (P < 0.05) higher than the organic carbon contentof RH (1.0 mm) particle size (224.20g/kg).Organic carbon content of RH (1.0 mm) was significantly higher than the contentof BCW (168.53g/kg).

Total nitrogen content of RH (0.5 mm) particle size(22.40 g/kg) was not significantly (P<0.05) different from the content of RH (2.0 mm) particle size (22.30g/kg) and RH (1.0 mm) particle size (22.10g/kg). They were significantly (P < 0.05) higher than the total nitrogen content of BCW (20.96 g/kg).The total nitrogen content of BCW was significantly higher than the content of SD (2.0 mm) particle size (5.70g/kg). But the total nitrogen content of SD (2.0 mm) was not significantly different from the content of SD (1.0 mm) particle size (5.67 g/kg). However, the total nitrogen contents in the above mentioned materials were significantly higher than the contentof SD (0.5 mm) particle size (5.01g/kg).

The carbon/nitrogen (C/N) ratio of SD (0.5 mm) particle size (66:1) was significantly (P<0.05) higher than its valuein SD (1.0 mm) particle size (55:1).This was higher than the C/N ratio of SD (2.0 mm) particle size (43:1). The C/N ratios in the three particle sizes of sawdust were higher than the value in RH (0.5 mm) particle size (16:1).The C/N ratio of RH (0.5 mm) was higher than the C/N ratio of RH (2.0 mm)particle size

(11:1). However, the C/N ratio of RH (2.0 mm) was not significantly different from the value obtained in RH(1.0 mm) particle size (10:1).They were significantly higher than the C/N ratioof BCW (8:1).

The calcium content of BCW (13637.0mg/kg) was significantly ($P < 0.05$) higher than its content in SD (0.5 mm) particle size (3650.0 mg/kg).This was not significantly different from the contents in SD (1.0 mm) particle size (3636.3mg/kg)and SD (2.0 mm) particle size (3566.7mg/kg).Calcium contents ofBCW and SDmaterials were significantly higher than the content in RH (2.0 mm)particle size (2196.3mg/kg).Butthe calcium content of RH (2.0 mm) particle size was not significantly different from its contents in RH (0.5 mm) particle size (2193.3mg/kg) and RH (1.0 mm) particle size (2188.3mg/kg).

Magnesium content was significantly ($P<0.05$) higher inBCW (2736.0 mg/kg) than in SD(2.0 mm) particle size (728.3mg/kg). Magnesium content in SD (2.0 mm) was not significantly different from the contents in SD (1.0 mm) particle size (720.7mg/kg)and SD (0.5 mm) particle size (716.7mg/kg). Magnesium contentsofBCW and SD materials weresignificantly higher than the content in RH (1.0 mm) particle size (439.0mg/kg).This was not significantly different from the contents in RH (0.5 mm) particle size (435.0mg/kg)and RH (2.0 mm) particle size (432.7mg/kg).

The sodium content in BCW (307.7mg/kg)was significantly ($P<0.05$) higher than the content obtained in RH (1.0 mm) particle size (219.3mg/kg).This was not significantly different from the contents inRH(0.5 mm) particle size

(214.3mg/kg)andRH(2.0 mm) particle size (212.0mg/kg).Theabove values were significantlyhigher than the valuein SD (1.0 mm) particle size(92.3mg/kg) butthiswas not statistically different from the values in SD (2.0 mm) particle size (92.3mg/kg)and SD (0.5 mm) particle size (89.8mg/kg).

Potassium content was significantly ($P<0.05$) higher in BCW (4990.80mg/kg) than in RH (1.0 mm) particle size (3475.7mg/kg).But the content in RH (1.0 mm) was not significantly different from the contents in RH (0.5mm) particle size (3401.0mg/kg)and RH (2.0 mm) particle size (3336.3mg/kg).However, the K contentsinthe different particle sizes of RH werenot significantly different from the content inSD (0.5mm) particle size (3236.7mg/kg).The content in SD (0.5 mm) was not also different from the content in SD (2.0 mm) particle size(3182.3mg/kg).Similarly, the K content in SD (2.0 mm) was not significantly different from the content in SD (1.0 mm) particle size (3089.2mg/kg).

The phosphorus content in SD (0.5 mm) particle size (212.2mg/kg) was not significantly ($P<0.05$) different from the contents in SD (2.0 mm) particle size (204.3mg/kg) andSD (1.0 mm) particle size (204.3mg/kg). However, phosphorus contentsin the three particle sizes of sawdust were significantly higher than the content in RH (1.0 mm) particle size (162.5mg/kg).The P content in RH (1.0 mm) was not significantly different from the contents in RH (0.5 mm) particle size (160.4mg/kg) and RH (2.0 mm)particle size(160.3mg/kg). Phosphorus content in RH (2.0 mm) was significantly ($P < 0.05$) higher than the content in BCW (67.1mg/kg).

4.3 Micronutrient contents of fresh rice husk, sawdust and battery cage waste used in the composting process

The micronutrient contents of fresh rice husk, sawdust and battery cage wasteused in the composting process are presented in Table 2.The zinc content in RH (0.5 mm) particle size (133.5mg/kg)was not significantly ($P<0.05$) different from the content obtained in RH (1.0 mm) particle size (132.1 mg/kg).But their values were significantly higher than the content in RH (2.0 mm) particle size(129.3mg/kg).The Zn contentofRH(2.0 mm)particle size was significantlyhigher than the content in SD (0.5 mm) particle size (126.2mg/kg).The content in SD (0.5 mm) was not significantly different from the content in SD (2.0 mm) particle size (125.3mg/kg)and this was not significantly different from the content in SD (1.0 mm) particle size (125.2mg/kg).The above values were significantly higher than their contents in BCW (123.0 mg/kg).

Manganese contents werenot significantly ($P<0.05$) different in RH (0.5 mm) particle size (86.3mg/kg)and RH (1.0 mm) particle size (86.1mg/kg). These values were not also different from the value inRH (2.0 mm) particle size (85.3mg/kg).They were significantly higher than the content of SD (1.0 mm) particle size (83.2 mg/kg).The manganese content in SD(1.0 mm) particle size was not significantly differentfrom the content in BCW (82.8mg/kg).However, the Mn content of BCW was significantly higher thanits contentin SD (2.0 mm) particle size (80.3mg/kg).Manganese content in SD (2.0 mm) was not significantly different from the content in SD (0.5 mm) particle size (80.3mg/kg).

The copper content in RH (0.5 mm) particle size (65.9mg/kg) was not significantly ($P<0.05$) different from the content in RH (1.0 mm) particle size (65.4mg/kg).

TABLE 2

Particle sizes and micronutrient contents of rice husk, sawdust and battery cage waste used in the composting process

Organic material	Micronutrient Zn	Mn	Cu	**Fe**
	←	(mg/kg)		→
Rice Husk (RH)				
0.5mm	133.50a	86.27a	65.86a	1.81a
1.0mm	132.07a	86.07a	65.44a	1.80a
2.0mm	129.27b	85.27a	63.60b	1.77a
Saw Dust (SD)				
0.5mm	126.23c	80.27c	62.44c	1.46c
1.0mm	125.17cd	83.21b	61.57c	1.40c
2.0mm	125.30cd	80.33c	61.23c	1.36c
Battery Cage Waste (BCW)	123.0d	82.82b	57.7d	1.58b

Means with the same superscripts along the same column are not significantly different ($p<0.05$), RH = rice husk, SD = sawdust, BCW = battery cage waste

The copper content in RH (1.0 mm) particle size was significantly higher than the content in RH (2.0 mm) particle size material (63.6 mg/kg).This was higher than the content in SD (0.5 mm) particle size (62.4mg/kg) but that was not significantly different from the content in SD (1.0 mm) particle size (61.6 mg/kg). Copper content of SD (1.0 mm) particle size was not also significantly different from the content in SD (2.0 mm) particle size (61.2mg/kg).But thecontent in SD (2.0 mm) was higher than the content in BCW (57.7 mg/kg).

The iron content in RH (0.5 mm) particle size (1.81mg/kg) was not significantly different from the contents obtained in RH (1.0 mm) particle size (1.80mg/kg)and RH (2.0 mm) particle size (1.77mg/kg).They were significantly higher than the content in BCW (1.58mg/kg). The iron contents ofRH and BCW materials weresignificantly ($p < 0.05$) higher than itscontent in SD (0.5 mm) particle size (1.46mg/kg).Iron content in SD (0.5 mm) was not significantly different from the contents in SD (1.0 mm) particle size (1.40mg/kg) and SD (2.0 mm) particle size (1.36mg/kg).

Generally, the pH values of the composting materials rangedfrom slightly acidic (6.20) in rice husk with 0.5 mm particle size to strongly alkaline (9.93) in battery cage waste (BCW). This pH range is in line with the report of Krogmann *et al.* (2010) who gave the pH of municipal solid waste to be alkaline and thepH of bio-wastes was slightly acidic. The values of electrical conductivity were low in all the composting materialsranging from 0.03to 0.70 dS/m.Organic carbon ranged from 168.53 in BCW to 351.53 g/kg in rice husk with 0.5 mm particle size. Total nitrogen was high in all the composting materials and ranged from 5.01in sawdust with 0.5 mm particlesize to 22.4 g/kgin rice husk with 0.5 mm particle size. The carbon to nitrogen (C/N) ratio of battery cage waste (8:1) was lower than the C/N ratio of rice husk particles (10:1 – 16:1) but those of sawdust particles were above mineralization level (43:1 – 66:1). The C/N ratio of poultry manure is in line with the findings of Ekundayo and Olayinka (2016). The C/N range of rice husk is in line with the report of Okonkwo *et al.* (2011) while the range of sawdust is in consonance with the findings of Effiong *et. al.* (2012) and Ekong *et. al.*(2017).Carbon/nitrogen ratio and particle size of organic material determine the rate of decomposition of organic materials and the quality of the cured compost. Michel *et al.*(1996) reported that the initial C/N ratio of organic materials is one of the most important factors influencing compost quality. Kumar *et al.* (2010) reported that initial C/N ratios of 25:1 – 30:1 are considered ideal for composting. Agnew and Leonard (2003) observed that composting process might be efficiently developed when substrates with C/N ratios in range of 25 – 30 are used. Nevertheless, the C/N ratio of organic materials between 25:1 and 40:1 (Dougherty, 1999) can favour high growth of microorganisms and their efficient processing of degradable organics.Mina *et al.* (2012) evaluated the effect of particle size and composting period on C/N ratio of Date-palm waste and reported that organic carbon content in wastes reduced in 0 - 5 mm compost than in 10 – 20 mm particle size compost. On the other hand, total nitrogen increased in 10 – 20 mm compost than in 0 – 5 mm compost. They observed that particle size of organic materials affect the time required for compost maturity and the quality of the cured compost. Large size particles reduce surface area of composting materials for microbial attack (Zia *et al.*, 2003) which slows down or may stop composting process altogether. Organic materials with medium to coarse texture, equivalent to particle sizes distribution between 0.25 and 2.5 mm was reported by Benito *et al.* (2005) to be the best as this allow retention of enough available water and adequate air content for composting.The composting materials recorded highcontentsof plant nutrients. Potassium (K)content ranged from 3089.2in sawdust with 1.0 mm particle size to 4990.8 mg/kg in BCW. Calcium content ranged from 2188.3 in rice husk with 1.0 mm particle size to 13,637.0 mg/kg in poultry manure (BCW). Magnesium ranged from432.7 in rice husk with 2.0 mm particle size to 2736 mg/kg in BCW.Sodium content in poultry manure (307.7 mg/kg) was higher than those in the three particle sizes of rice husk (212.0 – 219.3 mg/kg) and sawdust (89.8 – 92.3 mg/kg). The amount of phosphorus in BCW (67.1 mg/kg) was lower than the values recorded for rice husk (160.3 – 162.5 mg/kg) and sawdust (204.3 – 212.2 mg/kg).The Ca, Mg, K and Na contents in battery cage waste were significantly ($P < 0.05$) higher than values obtained in rice husk and sawdust. This may be as a result of the high contents of these elements in the feed formulation for the birds whose litter was used in the composting process.

Micronutrient contents in the composting materials were all high except iron. The zinc content ranged from 123.0 in BCW to 133.5 mg/kg in rice husk with 0.5 mm particle size.This was followed by the content of manganese which ranged from 80.3 in sawdust with 0.5 mm particle size to 86.3 mg/kg in rice husk with 0.5 mm particle size. Copper content ranged from 57.7 in BCW to 65.9 mg/kg in rice husk with 0.5 mm particle sizewhile the content of iron ranged from 1.36 in sawdust with 2.0 mm particle size to 1.81 mg/kg in rice husk with 0.5 mm particle size. The micronutrients (Zn, Cu, Mn and Fe)were significantly ($P < 0.05$) higherin the various particle sizesof rice husk than the rest of the materials.Micronutrients are essential elements for crop production and food quality and they are released through the biological degradation of organic materials by soil microorganisms (Erhart and Hartl, 2010). The composting materials were subjected to composting process for adequate mineralization of the nutrients when applied to the soil for crop production.

4.4. Chemical properties and moisture content of different compost treatments at 4 and 8 weeks after composting (WAC)

The chemical properties of the prepared composts at 4 and 8 weeks after composting (WAC) are presented in Tables 3 and 4.The chemical properties of the composts at 4 and 8 weeks after composting were significantly (P<0.05) higher in the periods of study compared to the fresh composting materials, indicating that the compost types, particle sizes and composting ratios had positive impact on the chemical properties of the prepared composts. Mean separation was done using Duncan's Multiple Range Test (DMRT). The mean values which were significantly different were categorized based on the superiority of the superscript attached to each level of treatment.

4.4.1 The pH of compost treatments at 4 and 8 weeks after composting (WAC)

The pH of compost treatments at 4 WAC was not significantly ($P < 0.05$) different in RH/BCW (2.0 mm) 1:16 compost and RH/BCW (2.0 mm)1:8 compost.These pH values were not also significantly different from the values ofRH/BCW (2.0 mm)1:4 compostand RH/BCW (1.0 mm) 1:4 compost.They were not different from the values ofRH/BCW (0.5 mm) 1:16 compost and SD/BCW (0.5 mm)1:8 compost.These values were not also different from the values of SD/BCW (1.0 mm) 1:4 compost and SD/BCW (2.0 mm) 1:4 compost as well as SD/BCW (2.0 mm) 1:8 compost.These pH values were significantly higher than the values in the remaining compost treatments. However, the pH values in some of the remaining compost treatments were not significantly different. The lowest pH value was obtained in RH/BCW (0.5 mm) 1:1 compost at 4 WAC.

TABLE 3

Chemical properties and moisture content of differentcompost treatments at 4 weeks after composting (WAC)

Treatment	pH	EC µs/cm	OC (g/kg)	TN (g/kg)	C/N	Ca →	Mg	Na (mg/kg) ←	K	P	MC (%)	Zn →	Mn (mg/kg) ←	Cu	Fe
RH/BCW 0.5mm 1:1	9.1h	3718.8i	33.0c	1.4defgh	23.6ab	6110.0b	1597.5h	1233.5ef	1584.5c	988.2j	35.0l	55.0c	11.6hij	12.2e	323.0a
RH/BCW 0.5mm 1:4	9.4cdefg	4237.5fg	28.9h	1.4defgh	20.6abc	4620.0d	1262.5j	1290.5bc	1636.5c	975.0j	48.3a	56.5b	14.1ab	13.1bc	62.3g
RH/BCW 0.5mm 1:8	9.4cdefg	4452.5de	25.5k	1.2fghi	21.3ab	3890.0g	1075.0l	1329.0ab	1801.0ab	846.9k	43.2e	51.9ef	11.8ghi	12.9cb	31.0p
RH/BCW 0.5mm 1:16	9.6ab	3015.0l	23.1n	1.1i	21.0bcd	2675.0l	750.0m	1317.0abc	1795.0ab	853.1k	48.4a	51.6f	13.3def	11.3f	31.7o
RH/BCW 1.0mm 1:1	9.3def	3055.0l	32.4d	1.4defgh	23.1a	3705.0hi	1010.0l	1274.0de	1752.0ab	975.0j	40.7g	49.6gh	11.2ijk	12.1e	31.6o
RH/BCW 1.0 mm 1:4	9.6ab	4357.5fe	30.1f	1.3efghi	23.2a	4570.0e	1058.5l	1306.5abc	1763.5ab	840.5k	38.8i	54.2d	13.6bcd	13.3bc	31.7o
RH/BCW 1.0 mm 1:8	9.5bcde	4552.5d	24.3l	1.2fghi	20.3cde	4215.0f	1260.0j	1332.0ab	1819.0ab	707.0l	39.5h	52.3e	11.0jk	13.0bc	42.3m
RH/BCW 1.0 mm 1:16	9.5bcde	4081.3h	17.4q	0.9j	19.3bcd	3985.0fg	1159.0k	1379.0a	1791.0ab	1754.cd	39.0hi	49.1hi	14.0ab	11.2fg	41.0n
RH/BCW 2.0 mm 1:1	9.5bcde	4925.0b	28.3i	1.2fghi	23.6abc	4225.0f	1050.0l	1377.0a	1783.0ab	1993.8a	44.0d	46.3l	13.1ef	11.2fg	62.2g
RH/BCW 2.0 mm 1:4	9.6ab	4176.3hg	38.3b	1.6bc	24.0a	4145.0fg	1345.0i	1311.0abc	1770.0ab	1832.5cb	47.8ab	44.9m	13.3def	13.5ab	208.5b
RH/BCW 2.0 mm 1:8	9.6ab	4135.0hg	32.4d	1.4defgh	23.1ab	4105.0fg	1008.0l	1331.0ab	1741.0b	1792.5c	41.8f	48.0j	13.3def	14.0a	109.2d
RH/BCW 2.0 mm 1:16	9.8a	1521.3p	29.5g	1.3efghi	22.7abc	6175.0b	1775.0g	1282.0cd	1753.0ab	1334.0f	47.3b	50.0g	12.1gh	11.1fg	46.7l
SD/BCW 0.5mm 1:1	9.4cdefg	4948.8b	39.3a	1.9a	20.7bcd	5411.3c	1730.0g	1357.0ab	1756.0ab	1208.1g	42.2f	50.2g	12.3g	11.2fg	62.3g
SD/BCW 0.5mm 1:4	9.3def	7965.0a	23.7m	1.4defgh	17.0def	8185.0a	2540.0d	1369.0ab	1823.0a	1765.0cd	35.9k	46.9k	14.0ab	11.0fg	123.3c
SD/BCW 0.5 mm 1:8	9.6ab	4390.0e	25.5k	1.6bc	16.0fgh	4680.0d	2140.0f	1231.0f	1746.0ab	1678.1d	40.3g	59.1a	11.4ijk	11.4f	62.3g
SD/BCW 0.5mm 1:16	9.5bcde	1640.0p	17.4q	1.2fghi	14.5gh	1835.0m	1057.5l	1368.5ab	1761.5ab	1825.0c	46.2c	45.1m	11.1jk	10.7g	46.9l
SD/BCW 1.0 mm 1:1	9.4cdefg	1627.5p	31.8e	1.8ab	17.7def	1732.5n	1159.0k	1328.0abc	1816.0ab	1910.0b	42.0f	47.1k	13.9ab	10.9fg	46.6l
SD/BCW 1.0 mm 1:4	9.6ab	2410.0m	19.7p	1.3efghi	15.2fgh	2580.0l	1050.0l	1308.0abc	1789.0ab	1519.4e	38.3i	51.6f	14.3a	11.3f	42.4m
SD/BCW 1.0 mm 1:8	9.5bcde	4695.0c	19.7p	1.3efghi	15.2fgh	4910.0d	3150.0c	1297.0bc	1776.0ab	1358.1f	35.8k	43.7n	13.4def	11.3f	51.4i
SD/BCW 1.0 mm 1:16	9.4cdefg	2215.0n	10.4u	0.6j	17.3efg	2600.0l	9145.0a	1275.0de	1780.0ab	1316.9f	41.9f	48.6ij	11.8ghi	11.0fg	47.9k
SD/BCW 2.0 mm 1:1	9.2gh	1925.0o	26.6j	1.5cde	17.7def	2150.0m	1802.5g	1331.5ab	1811.5ab	1135.6hi	34.8l	46.0l	13.1ef	13.9a	60.8h
SD/BCW 2.0 mm 1:4	9.6ab	3065.0l	22.6o	1.2fghi	18.8def	3210.0k	825.0m	1297.0bc	1767.0ab	1078.1i	35.1l	49.1hi	13.7abc	13.5ab	79.1e
SD/BCW 2.0 mm 1:8	9.6ab	3535.0j	14.5t	1.5cdef	10.0i	3640.0ij	2245.0e	1273.0de	1771.0ab	1285.6fg	37.2j	50.1g	13.3def	12.3de	63.5f
SD/BCW 2.0 mm 1:16	9.5bcde	3215.0k	17.4q	1.3efghi	13.4h	3390.0jk	4835.0b	1300.0abc	1773.0ab	1185.5h	44.3d	48.5ij	12.3g	10.9fg	50.3j

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

TABLE 4

Chemical properties and moisture content of differentcompost treatments at 8 weeks after composting (WAC)

Treatment	pH	EC (µs/cm)	OC (g/kg)	TN (g/kg)	C/N	Ca	Mg	Na (mg/kg)	K	P	MC (%)	Zn	Mn (mg/kg)	Cu	Fe
RH/BCW 0.5 mm 1:1	11.4d	5532.5b	19.3i	1.0h	19.3bcd	3682.5m	1282.5h	1248.5bc	1728.5ab	895.0g	50.8a	62.4abc	11.6hij	12.2e	322.4a
RH/BCW 0.5 mm 1:4	10.8hi	5760.0a	19.4i	1.1gh	17.6def	2090.0n	650.01	1257.0bc	1727.0ab	1527.5c	47.7b	64.6ab	14.1ab	13.1bc	61.7g
RH/BCW 0.5 mm 1:8	10.9gh	2100.0m	17.6k	1.1gh	16.0f	4040.01	1240.0hi	1206.0bcd	1700.0ab	961.9f	41.5hi	55.5efg	11.8gh	12.9c	30.8s
RH/BCW 0.5 mm 1:16	10.9gh	4782.5c	27.2c	1.4abc	19.4bcd	2112.5n	812.5j	1263.5ab	1741.5a	1128.1e	43.2f	61.7bc	13.3de	11.3g	30.9rs
RH/BCW 1.0 mm 1:1	11.0fg	5545.0b	18.3j	1.2efg	15.3f	2095.0n	745.0k	1243.0bc	1720.0ab	954.4fg	39.31	58.2cd	11.2ij	12.1e	31.0r
RH/BCW 1.0 mm 1:4	11.2e	2987.51	6.81	0.5i	13.7g	8097.5a	2317.5a	1243.5bc	1725.5ab	1113.1e	40.2k	63.0abc	13.6bc	13.3bc	31.0r
RH/BCW 1.0 mm 1:8	10.7j	1855.0n	20.3h	1.0h	20.3abc	8065.0a	2065.0b	1197.0cd	1683.0ab	1127.5e	41.9gh	58.2cd	11.0k	13.0bc	41.8o
RH/BCW 1.0 mm 1:16	11.8bc	3407.5j	27.4c	1.4abc	19.6abc	6877.5b	1777.5c	1225.5bc	1700.5ab	1390.0d	44.1e	56.1de	14.0ab	11.2fg	40.4q
RH/BCW 2.0 mm 1:1	11.8bc	4590.0d	23.9f	1.3cde	18.4cde	5330.0f	1220.0i	1228.0bc	1707.0ab	814.4hi	46.6c	53.5fg	13.1ef	11.2fg	61.7g
RH/BCW 2.0 mm 1:4	11.8bc	4257.5f	27.1c	1.5ab	18.1bcd	6107.5c	1607.5e	1230.5bc	1729.5ab	1764.8a	38.81	54.6fg	13.3de	13.5ab	207.6b
RH/BCW 2.0 mm 1:8	12.2a	3695.0h	28.9b	1.6a	18.1bcd	6085.0c	1585.0e	1206.0bcd	1703.0ab	1678.8b	45.7d	55.7def	13.3de	14.0a	108.6d
RH/BCW 2.0 mm 1:16	11.9b	3400.0j	27.3c	1.5ab	18.2bcd	6870.0b	1770.0c	1218.0bc	1693.0ab	1382.5d	44.0e	56.3de	12.1gh	11.1fg	46.3n
SD/BCW 0.5 mm 1:1	11.7c	4602.5d	24.1f	1.2efg	20.1abc	5342.5f	1232.5hi	1240.5bc	1719.5ab	826.9h	46.7c	58.5bcd	12.3g	11.2fg	61.6gh
SD/BCW 0.5 mm 1:4	11.7c	4340.0e	23.2g	1.2efg	19.3bcd	860.0o	2260.0a	1185.0de	1687.0ab	763.1ij	40.4jk	52.3hi	14.0ab	11.0fg	122.9c
SD/BCW 0.5 mm 1:8	10.4k	2067.5m	29.9a	1.4abc	21.4a	5326.5f	1229.5hi	1317.5a	1722.5ab	753.8j	45.1d	67.9a	11.4ij	11.4f	61.5h
SD/BCW 0.5 mm 1:16	11.2e	4087.5g	23.7fg	1.4abc	17.0ef	5657.5d	1457.5f	1177.5e	1675.5b	729.4j	36.5n	50.3i	11.1jk	10.7g	46.6m
SD/BCW 1.0 mm 1:1	11.2e	4570.0d	24.3f	1.3cde	19.0bcd	5260.0g	1360.0g	1185.0de	1689.0ab	731.9j	43.9e	52.5ghi	13.9ab	10.9fg	46.3n
SD/BCW 1.0 mm 1:4	10.5k	4057.5g	25.1e	1.4abc	17.9def	4907.5h	1607.5e	1255.5bc	1733.5ab	769.2hi	43.1f	61.2bc	14.3a	11.3fg	41.6p
SD/BCW 1.0 mm 1:8	10.7j	2985.01	27.4c	1.5ab	18.3bcd	4305.0j	1585.0e	1242.0bc	1727.0ab	765.2ij	41.1ij	53.2fg	13.4cd	11.3fg	50.6j
SD/BCW 1.0 mm 1:16	11.4d	3300.0k	25.7d	1.4abc	18.4bcd	5570.0e	1690.0d	1220.0bc	1690.0ab	728.7j	44.2e	54.9fg	11.8gh	11.0fg	47.41
SD/BCW 2.0 mm 1:1	10.8hi	2100.0m	28.8b	1.6a	18.0bcd	3680.0m	1580.0e	1210.0bc	1696.0ab	780.2hi	37.8m	53.2fg	13.1ef	13.9a	60.3i
SD/BCW 2.0 mm 1:4	11.4d	3557.5i	27.6c	1.5ab	18.4bcd	4107.5k	1457.5f	1243.5bc	1731.5ab	763.9ij	40.3k	58.8bc	13.7abc	13.5ab	78.2e
SD/BCW 2.0 mm 1:8	11.8c	4395.0e	25.7d	1.3cde	19.8abc	4685.0i	1725.0cd	1227.0bc	1695.0ab	755.1ij	42.3g	57.7cd	13.3de	12.3de	62.9f
SD/BCW 2.0 mm 1:16	11.0fg	4625.0d	28.9b	1.4abc	20.6ab	4925.0h	1395.0g	1219.0bc	1681.0ab	724.7j	42.2g	54.4fg	12.3g	10.9fg	49.8k

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

The pH of the compost treatments at 8 WAC was significantly ($P < 0.05$) higher in RH/BCW(2.0 mm) 1:8 compost than in RH/BCW (2.0 mm) 1:16 compost.The pH level of RH/BCW (2.0 mm) 1:8 compost increased by 27% at 8 WAC while the reaction of RH/BCW (2.0 mm) 1:16 increased by 21%. These pH values were not significantly different from the pH valuesof RH/BCW (2.0 mm) 1:4 compost, RH/BCW (2.0 mm) 1:1 compost and RH/BCW (1.0 mm) 1:16 compost. The percentage increases in the pH level of RH/BCW (2.0 mm) 1:4 compost, RH/BCW (2.0 mm) 1:1 compost and RH/BCW (1.0 mm) 1:16 compost were 23, 24 and 24%, repectively.The pH values in the above listed composts were significantly higher than the values ofSD/BCW (0.5 mm) 1:1 compost, SD/BCW (0.5 mm) 1:4 compost and SD/BCW (2.0 mm) 1:8 compost.Their percentage increases in the pH level were 29, 26 and 23%, respectively.Their pH values werealso significantly higher than the values of RH/BCW (0.5 mm) 1:1 compost, SD/BCW (1.0 mm) 1:16 compost andSD/BCW (2.0 mm)1:4 compost.These compost treatments recorded the percentage increases in their pH level at 8 WAC as 25, 21 and 19%, respectively. The pH valuesof the above listed composts weresignificantly higher than its value inRH/BCW (1.0 mm) 1:4 compost, SD/BCW (0.5 mm) 1:16 compostand SD/BCW (1.0 mm) 1:1 compost.The percentage increases in the pH level of these compost treatments were 17, 18 and 19%, respectively. The pH value of SD/BCW (1.0 mm) 1:1was significantly ($P < 0.05$) higher than the pH values of RH/BCW (1.0mm) 1:1 compost and SD/BCW (2.0 mm) 1:16 compost.The pH level of RH/BCW (1.0 mm) 1:1 compost increased by 18% at 8 WAC while the pH of SD/BCW (2.0 mm) 1:16 compost increased by 17%. The pH valueof SD/BCW (2.0 mm) 1:16 compost was significantly higher than the value in RH/BCW (0.5 mm) 1:8 compost and RH/BCW (0.5 mm) 1:16 compost. Their pH levels increasedby 16 and 14%, respectively and theirpH valueswere higher than the value of SD/BCW (2.0 mm) 1:1 compost.The pH level in SD/BCW (2.0 mm) 1:1 compost increased by 17% butitspH value was not significantly different from the pH value ofRH/BCW (0.5 mm) 1:4 compost with percentage increase of 15%.Their values weresignificantly higher than the value ofRH/BCW (1.0 mm) 1:8 compostwith percentage increase of 13%. Its pHvalue was not significantly different from the pH value ofSD/BCW (1.0 mm)1:8 compost but this was significantly higher than the value of SD/BCW(0.5mm) 1:8 compost and SD/BCW (1.0 mm) 1:4 compost. The pH levels of SD/BCW (1.0 mm) 1:8 compost increased by 13%, SD/BCW (0.5 mm) 1:8 compost increased by 8% and SD/BCW (1.0 mm) 1:4 compost increased by 9%.

4.4.2 Electrical conductivity of compost treatments at 4 and 8 weeks after composting (WAC)

The EC of the compost treatments was significantly ($P < 0.05$) higher in SD/BCW(0.5 mm) 1:4 compost than in SD/BCW (0.5 mm) 1:1 compost at 4 WAC. The EC value of SD/BCW (0.5 mm) 1:1was not significantly differentfrom the value in RH/BCW (2.0 mm) 1:1 compost.But thesevalues were significantly ($P < 0.05$) higher than the value in SD/BCW(1.0 mm) 1:8 compost which was significantly ($P < 0.05$) higher than the EC valuesinRH/BCW (1.0 mm) 1:8 compost and RH/BCW (0.5 mm) 1:8 compost.These EC values weresignificantly ($P < 0.05$) higher than the ECvaluesin the remaining compost treatments. The lowest EC value was obtained in SD/BCW (1.0 mm) 1:1compost which was not significantly different from values inSD/BCW (0.5 mm) 1:16 compost andRH/BCW (2.0 mm) 1:16 compost at 4 WAC.

The EC value of RH/BCW (0.5 mm) 1:4 compost at 8 WAC was significantly ($P < 0.05$) higher than the value in RH/BCW (0.5 mm) 1:1 compost.The EC valueinRH/BCW (0.5 mm) 1:4 compost increased by 36% at8 WAC andthe value in

RH/BCW (0.5 mm) 1:1compost increased by 49%.The EC value in RH/BCW (0.5 mm) 1:1 compost was not significantly different from the value of RH/BCW (1.0 mm) 1:1 compost.Butthesevalues were significantly ($P < 0.05$) higher than the values inthe rest of the compost treatments. There were various percent increases and reductions in the remaining compost treatments at 8 WAC. The least EC value was obtained in RH/BCW (1.0 mm) 1:8 compost whose value decreased by 59% at 8 WAC.

4.4.3 Organic carbon contentsof composts at 4 and 8 weeks after composting (WAC)

The organic carbon contentin SD/BCW (0.5 mm) 1:1 compost was significantly ($P < 0.05$) higher than its content in RH/BCW (2.0 mm) 1:4 compost at 4 WAC.The value in RH/BCW (2.0 mm) 1:4 compost was significantly ($P < 0.05$) higher than thevalue in RH/BCW (0.5 mm)1:1 compost and this was significantly ($P < 0.05$) higher than the organic carbon content inRH/BCW (1.0 mm) 1:1 compost.However, this content was not significantly different from that of RH/BCW (2.0 mm) 1:8 compost.These values were significantly ($P < 0.05$) higher than the organic carbon content in the remaining compost treatments. The lowest organic carbon content was obtained in SD/BCW (1.0 mm) 1:16 compost at 4 WAC.

The organic carbon content in SD/BCW (0.5 mm) 1:8 compost at 8 WAC was significantly ($P < 0.05$) higher than the content in RH/BCW (2.0 mm) 1:8 compost.The organic carbon content of SD/BCW (0.5 mm) 1:8 compost decreased by 17% while that of RH/BCW (2.0 mm) 1:8 compost decreased by 11% at 8 WAC.However, the organic carbon content inRH/BCW (2.0 mm) 1:8 compost was not significantly different from the contentsin SD/BCW (2.0 mm) 1:1 compost andSD/BCW (2.0 mm) 1:16 compost.These values were significantly ($P < 0.05$) higher than the valuesin other compost treatments. However, the organic carbon contents in some of the remaining compost treatments were not significantly higher than each other. There were percent increases and decreases in the remaining compost treatments at 8 WAC. The lowest organic carbon content was obtained inRH/BCW (1.0 mm) 1:4 compost whose value decreased by 77% at 8 WAC.

4.4.4 Total nitrogen contentsof composts at 4 and 8 weeks after composting (WAC)

The total nitrogen content of the compost treatments at 4 WAC showed that SD/BCW (0.5 mm) 1:1 compostwas not significantly different from the content in SD/BCW (1.0 mm) 1:1 compost.These values weresignificantly ($P < 0.05$) higher than the contentsin SD/BCW (0.5 mm) 1:8 compost and RH/BCW (2.0 mm) 1:4 compost.Thesevalues were significantly ($P < 0.05$) higher than thevaluesin the rest of the compost treatments. However, the total nitrogen contents in some of the remaining compost treatments were not significantly different. The lowest total nitrogen content was obtained in RH/BCW (1.0 mm) 1:16 compost which was not significantly different from the content in SD/BCW (1.0 mm) 1:16 compost at 4 WAC.

At 8 WAC, the total nitrogen content in RH/BCW (2.0 mm) 1:8 compost was not significantly ($P < 0.05$) differentfrom the content inSD/BCW (2.0 mm)1:1 compost. The nitrogen content in RH/BCW (2.0 mm) 1:8 compost increased by 14% while the content in SD/BCW (2.0 mm) 1:1 compostincreased by 7% at 8 WAC. Thesenitrogen contents were not statistically different from the content inSD/BCW (2.0 mm) 1:4 compost with 25% increase. Itscontent was not significantly different from the nitrogen content inSD/BCW (2.0 mm)1:16 compost with 8% increase at 8 WAC.These nitrogen contents were not significantly different from the content inSD/BCW (1.0 mm)1:8 compost 15% increase,SD/BCW (1.0 mm)1:4 compostwith 8% increase and RH/BCW (2.0 mm) 1:16 compost with 15% increase.Thesenitrogen remaining compost treatments were not significantly different. The lowest C/N ratio was obtained in SD/BCW (2.0 mm) 1:8 compost at 4 WAC.

At 8 WAC, the C/N ratio of SD/BCW (0.5 mm) 1:8 compost was not significantly ($P < 0.05$) different from the C/N ratios in SD/BCW (2.0 mm) 1:16 compost and RH/BCW (1.0 mm) 1:8 compost.The SD/BCW (0.5 mm) 1:8 compost recorded 34% increase in C/N ratio, SD/BCW (2.0 mm) 1:16 compost had 54% increase and no change in the C/N ratio of RH/BCW (1.0 mm) 1:8 compost at 8 WAC. These C/N ratios were not significantly different from the values in RH/BCW (1.0 mm)1:16 compost with 2% increase, SD/BCW (0.5 mm) 1:1 compost with 3% decrease. These C/N ratios were significantly higher than the value inRH/BCW (0.5 mm) 1:1 compost with 18% decrease. However, this ratio was not significantly different from the C/N ratio of RH/BCW (0.5 mm) 1:16 compost with 7% decrease.These ratios were not different from the ratios inRH/BCW (2.0 mm) 1:4 compost with 25% decreaseand RH/BCW (2.0 mm) 1:8 compostwith 22% decrease.These were not significantly different from the ratios in RH/BCW (2.0 mm)1:16 compost with 20% decrease,SD/BCW (0.5 mm) 1:4 compost with 14% increase,SD/BCW (1.0 mm) 1:1 compost with 7% increase. These values were not significantly different from the values inSD/BCW (1.0 mm) 1:8 compost with 20% increase,SD/BCW (1.0 mm) 1:16 compost with 6% increase,SD/BCW (2.0 mm) 1:1 compost with 2% increase,SD/BCW (2.0 mm) 1:4 compost with 2%decrease andSD/BCW (2.0 mm) 1:8 compost with 98% increase.But the C/N ratios of the listed composts were significantly ($P < 0.05$) higher than the ratio in RH/BCW (2.0 mm) 1:1 compost with 22% decrease. This ratio was significantly higher than the ratio in RH/BCW (0.5 mm)1:4 compost with 15% decrease but its value was not significantly different from the ratio in SD/BCW (1.0 mm) 1:4 compost with 18% increase. However, the C/N

4.4.8 Sodium contentsof compost treatments at 4 and 8 weeks after composting (WAC)

The sodium content in RH/BCW (1.0 mm)1:16 compost was not significantly differentthe content in RH/BCW (2.0 mm) 1:1 compostat 4 WAC. These contents were not also different from the contents in SD/BCW (0.5 mm) 1:4 compost, SD/BCW (0.5 mm) 1:16 compost, SD/BCW (0.5 mm) 1:1 compost,RH/BCW (0.5 mm) 1:8 compost. These values were not significantly higher than some sodium contentsin many compost treatments but higher than some in other compost treatments. The lowest content was recorded in SD/BCW (0.5 mm) 1:8 compost at 4 WAC.

At 8 WAC, sodium content was not significantly ($P < 0.05$) different in SD/BCW (0.5 mm) 1:8 compost and RH/BCW (0.5 mm) 1:16 compost.Sodium content in SD/BCW (0.5 mm) 1:8 compost increased by 7%, while the content in RH/BCW (0.5 mm) 1:16 compost decreased by 4% at 8 WAC. The sodium contents in these composts were significantly higher than the content in SD/BCW (1.0 mm) 1:4 compost which recorded 4% decrease at 8 WAC.Sodium contents in thesecompost treatments were not significantly different from the contentsin the rest of the compost treatments but the contents in the above listed compost treatments were significantly ($P < 0.05$) higher than the content in SD/BCW (0.5 mm) 1:16 compost with 14% decrease at 8 WAC. This compost treatment recorded the lowest sodium content at 8 WAC.

4.4.9 Potassium contentsof compost treatments at 4 and 8 weeks after composting (WAC)

The potassium content in SD/BCW (0.5 mm) 1:4 compost was not significantly ($P < 0.05$) different from the content in RH/BCW (0.5 mm) 1:8 compostat 4 WAC.These values were not significantly different from the contents in RH/BCW (0.5 mm)1:16

compost,RH/BCW (1.0 mm) 1:1 compostand RH/BCW (1.0 mm) 1:4 compost.Thesevalues were not also different from the contents in so many compost treatments but it was higher than the content in few compost tteatments at 4 WAC. The lowest content was obtained in RH/BCW (0.5 mm) 1:1 compostwhichwas not significantly different from the content in RH/BCW (0.5 mm) 1:4 compost at 4 WAC. The potassium content at 8 WAC in the compost treatments werenot significantly ($P < 0.05$) differentexcept in SD/BCW (0.5 mm) 1:16 compost. However, potassium content in RH/BCW (0.5 mm) 1:1 compost increased by 9% at 8 WAC. The potassium content in RH/BCW (0.5 mm) 1:4 increased by 6% while the remaining compost treatments had percent decreases ranging from 1 – 7% at 8 WAC.

4.4.10 Phosphorus contentsof compost treatments at 4 and 8 weeks after composting (WAC)

At 4 WAC the phosphorus content inRH/BCW (2.0 mm) 1:1 compost was significantly ($P < 0.05$) higher than the content in SD/BCW (1.0 mm) 1:1 compost.These contentswere significantly ($P < 0.05$) higher than the contentsin the remaining compost treatments. The least value was obtained in RH/BCW (1.0 mm) 1:8 compost at 4 WAC.

The phosphorus content of the compost treatments at 8 WACwas significantly ($P < 0.05$) higher in RH/BCW (2.0 mm) 1:4 compostthan in RH/BCW (2.0 mm) 1:8 compost. The P content in RH/BCW (2.0 mm) 1:4 compost decreased by 4% whereasP content in RH/BCW (2.0 mm) 1:8 compost decreased by 6% at 8 WAC. These phosphorus contents were significantly ($P < 0.05$) higher than the content in RH/BCW (0.5 mm) 1:4 compost with 57% increase at 8 WAC. This was higher than the content in RH/BCW (1.0 mm) 1:16 compost with 21% decrease whichwas not significantly different from the content in RH/BCW (2.0 mm) 1:16 compost with 4%

increase at 8 WAC.These phosphorus contents were significantly (P < 0.05) higher than the contentsinthe remaining compost treatments with various percent increases and decreases.The lowest contents were obtained in SD/BCW (0.5 mm) 1:16 compost and SD/BCW (0.5 mm) 1:8 compostwith 60 and 55% reduction, respectively.

4.4.11Zinc contents of compost treatments at 4 and 8 weeks after composting (WAC)

The zinc content at 4 WAC was significantly (P < 0.05) higher in SD/BCW (0.5 mm) 1:8 compost than in RH/BCW (0.5 mm) 1:4 compost.This content was significantly higher than the zinc content ofRH/BCW (0.5 mm) 1:1 compost which was significantly (P < 0.05) higher than the content in the rest of the compost treatments. The least content was obtained in SD/BCW (1.0 mm) 1:8 compost at 4 WAC.

At 8 WAC,the zinc contentswerenot significantly (P < 0.05) different in SD/BCW (0.5 mm) 1:8 compost with 15% increase,RH/BCW (0.5 mm) 1:4 compost with 14% increase, RH/BCW (0.5 mm) 1:1 compostwith 13%increase andRH/BCW (1.0 mm) 1:4 compost with 16% increase at 8 WAC.These contents were significantly higher than the contentsin the remaining compost treatments. The lowest content was recorded in SD/BCW (0.5 mm) 1:16 compostwith 12% increase at 8 WAC.

4.4.12Manganese contents of compost treatments at 4 and 8 weeks after composting (WAC)

At 4 WAC, manganese content in SD/BCW (1.0mm) 1:4 compostwas not significantly (P < 0.05) different from the contents in RH/BCW (0.5 mm) 1:4 compost, RH/BCW (1.0 mm) 1:16 compost,SD/BCW (0.5 mm) 1:4 compost, SD/BCW (1.0 mm) 1:1 compost and SD/BCW (2.0 mm) 1:4 compost.But these values were significantly (P < 0.05) higher than manganese contentsin the rest of the compost treatments. The least content was obtained in SD/BCW (0.5 mm) 1:16 and RH/BCW (1.0 mm) 1:8 compost.

At 8 WAC, the manganese contentswerenot significantly ($P < 0.05$) different in SD/BCW (1.0 mm) 1:4 compost, RH/BCW (0.5 mm) 1:4 compost, RH/BCW (1.0 mm) 1:16 compost,SD/BCW (0.5 mm) 1:4 compost,SD/BCW (1.0 mm) 1:1 compostand SD/BCW (2.0 mm) 1:4 compost.These contents were significantly higherthan manganese content in the remaining compost treatments. The lowest value was obtained in RH/BCW (1.0 mm) 1:8 compost at 8 WAC. The manganese contents at 8 WAC did not differ from its contents at 4 WAC, therefore there was no percent change.

4.4.13Copper contents of compost treatments at 4 and 8 weeks after composting (WAC)

At 4 WAC the copper contents in the composts werenot significantly ($P < 0.05$) different in RH/BCW (2.0mm) 1:8 compost,SD/BCW (2.0 mm) 1:1 compost, RH/BCW (2.0 mm) 1:4 compostand SD/BCW (2.0 mm) 1:4 compost.These copper contents were significantly higher than the contentin other compost treatments. The lowest value was recorded in SD/BCW (0.5 mm)1:16 compost at 4 WAC.

At 8 WAC the copper contentswerenot significantly ($P < 0.05$) different in RH/BCW (2.0 mm) 1:8 compost, SD/BCW (2.0 mm) 1:1 compost, RH/BCW (2.0 mm) 1:4 compostand SD/BCW (2.0 mm) 1:4 compost.However, these values were higher than the content in other compost treatments. The least value was obtained in SD/BCW (0.5 mm) 1:16 compost at 8 WAC. Copper contents at 8 WAC did not differ from its contents at 4 WAC.

4.4.14Iron contents of compost treatments at 4 and 8 weeks after composting (WAC)

At 4 WAC,iron content was significantly ($P < 0.05$) higher in RH/BCW (0.5mm) 1:1 compost than inRH/BCW (2.0 mm) 1:4 compost.Thesevalues werehigher than the contentsin the remaining compost treatments. The lowest value found in RH/BCW (0.5 mm) 1:8 compost at 4 WAC.

At 8 WAC, the iron content in RH/BCW (0.5 mm) 1:1 compost was significantly ($P < 0.05$) higher than the content inRH/BCW (2.0 mm) 1:4 compost.Thesecontentswere significantly ($P < 0.05$) higher than the contents in the remaining compost treatments. The least iron content was obtained in RH/BCW (0.5 mm) 1:8 compost at 8 WAC.

4.4.15 Moisture contents of compost treatments at 4 and 8 weeks after composting (WAC)

The moisture content of the compost treatments at 4 WAC varied significantly among the different compost piles. The moisture content of RH/BCW (0.5 mm) 1:4 compost was not significantly different from the contents in RH/BCW (0.5 mm) 1:16 compost and RH/BCW (2.0 mm) 1:4 compost. These values were significantly ($P < 0.05$) higher than the moisture content in the remaining compost treatments. The lowest value was obtained in RH/BCW (0.5 mm) 1:1 compost whose moisture content was not significantly different from the contents in SD/BCW (2.0 mm) 1:1 compost andRH/BCW (2.0 mm) 1:4 compost.

At 8 WAC the moisture content of RH/BCW (0.5 mm) 1:1 compost was significantly ($P < 0.05$) higher than the content in RH/BCW (0.5 mm) 1:4 compost. The moisture content in RH/BCW (0.5 mm) 1:1 compost increased by 45% while the content in RH/BCW (0.5 mm) 1:4 compost decreased by 1% at 8 WAC. The moisture contents in these composts were significantly higher than the contents in the remaining compost treatments with different percent increases and decreases. The lowest moisture content was obtained in SD/BCW (0.5 mm) 1:16 compost with 21% reduction at 8 WAC.

Generally, some of the chemical properties of the compost treatments at 8 weeks after composting (WAC) were higher than the values obtained at 4 WAC. The pH of all compost treatments at 8 WAC ranged from 10.4 – 12.2 which was at strongly alkaline range. The pH range is in line with the findings of Ayesha *et al.* (2016) who reported that alkaline pH is important parameter to evaluate compost maturity and stability. Composts with strongly alkaline property could be capable of neutralizing soil acidity. The electrical conductivity of all the compost treatments was high which could be attributed to the high pH value of the compost treatments. The organic carbon content of the composts ranged from 6.8 to 29.9 $gkg^{-1}$and total nitrogen ranged from 0.5 to 1.6 gkg^{-1} at 8 WAC. The C/N ratio of all the compost treatments ranged from 14:1 to 22:1 at 8 WAC. The lowest C/N ratio of 14:1 was obtained in RH/BCW (1.0 mm) 1:4 compost while the highest C/N ratio of 22:1 was obtained in SD/BCW (0.5 mm) 1:8 compost. The C/N ratio of RH/BCW composts at 8 WAC ranged from 14:1 in RH/BCW (1.0 mm) 1:4 compost to 20:1 in RH/BCW (1.0 mm) 1:8 and 1:16 composts lower than the C/N ratio of SD/BCW composts that ranged from 17:1 in SD/BCW (0.5 mm) 1:16 compost to 22:1 in SD/BCW (0.5 mm) 1:8 compost. The decrease in C/N ratios of the composts was reportedby Ogunwande (2011) who attributed the decrease to either the mineralization of the substrates present in the initial composting materials or an increase in total N content resulting from the concentration effect as carbon is biodegraded. The effects of C/N ratios of the three particle sizes of rice husk and sawdust in composting of poultry manure revealed that rice husk (RH) with initial C/N ratio of 10:1 to 16:1 combined with poultry manure with initial C/N ratio of 8:1 had the lowest C/N ratio while sawdust with initial C/N ratio of 43:1 to 66:1 combined with poultry manure with C/N ratio of 8:1 had higher C/N ratios than RH/BCW composts at 8 WAC. However, the C/N ratios of RH/BCW and SD/BCW composts at 8 WAC were within mineralization range capable of enhancing nutrients release and supporting sustainable crop production. Composts with final C/N ratio less than 25:1 showed an indication of maturity (Bernal *et al.*, 2009). The exchangeable bases (Ca, Mg, Na, K) and the phosphorus content as well as the micronutrients were high in all the compost treatments at 8 WAC. The highest contents of Ca and Mg at 8 WAC were obtained in RH/BCW (1.0 mm) 1:4 compost. The high contents of nutrients in the composts at 8 WAC is in line with the findings of Brady and Weil (2002) who reported that finished compost is generally more concentrated in nutrients than the initial combination of raw materials used.Although micronutrient contents (Zn, Mn, Cu, Fe) were high in all the compost treatments as reportedbut some of the micronutrients were higher at 4 WAC than at 8 WAC. The nutrient contents of the composts at 8 WAC were higher than the critical values needed in the soil. The nutrient contents in the composts can increase its availability and uptake by plants when applied to the soil.Organic fertilizer (Agbede *et al.*, 2015) was reported to improve the availability of essential nutrients in deficient soils and its base elements content capable of reducing soil acidity. Application of organic manure can sustain crop yields under continuous cropping through gradual nutrients release to improve the fertility of degraded soils (Mbonu and Afrifalo, 2006).

4.5 Pre-experiment soil analysis

The physical and chemical properties of soil used for the experiment are presented inTable 5. The soil of Akwa Ibom State University Teaching and Research Farm recorded 882, 30 and 88 g/kg sand, silt and clay, respectively. The pH was at 4.95.

Electrical conductivity of the soil was low (0.050 dS/m). The total N (1.20 gkg^{-1}), available P (4.26 $mgkg^{-1}$), exchangeable Ca (4.26$cmolkg^{-1}$), K (0.17$cmolkg^{-1}$) and Na (0.05$cmolkg^{-1}$) were low. The contents of organic matter (47.80gkg^{-1}) and exchangeable magnesium (1.12$cmolkg^{-1}$) were high compared to the critical values.The values of micronutrients; Zn (5.90 $mgkg^{-1}$), Mn (2.45 $mgkg^{-1}$), Cu (1.70 $mgkg^{-1}$) and Fe (170.4 $mgkg^{-1}$) were high.

The experimental soil was loamy sand in texture with very strongly acidic reaction. Highly acidic soils are detrimental to the growth and yield of arable crops. The high acidity of soils contribute to p-fixation, hence it unavailability to plants. This level of acidity could be attributed to the high amount of rainfall prevalent in the region which is capable of leaching the basic cations beyond the root zone. Such condition can reduce microbial fixation of atmospheric nitrogen (Gbadegesin *et al*., 2011).However, liming and application of organic fertilizers are recommended (Agbede *et al*., 2015) to reduce the acidity of such soils for sustainable crop production.

The total N, available P, exchangeable Ca, K and Na were low compared to the critical levels of 2.0 gkg^{-1} N, 10.0 $mgkg^{-1}$ P, 2.0 $cmolkg^{-1}$ Ca, and 0.20 $cmolkg^{-1}$Na and K reported by Chude *et al.* (2011). The low content of nitrogen in the soil of the study area could be attributed to high rate of microbial decomposition of organic matter, leaching of nitrates as well as it removal by the growing plants.

Amaranthus cruentus requires high amount of nitrogen (Adeoye *et al*., 2005) which is limited in the tropical soils.However, nitrogen can be sustainably added to the soil through compost.Phosphorus fixation is common in highly acidic soil which may be responsible for the low content of phosphorus in the experimental soil.

TABLE 5

Physical and chemical properties of soil before the experiment

Property		Value
Physical Properties:		
	Sand (gkg^{-1})	882
	Silt (gkg^{-1})	30
	Clay (gkg^{-1})	88
	Textural class	Loamy sand
Chemical Properties:		
	pH	4.95
	EC (dSm^{-1})	0.05
	Total N (gkg^{-1})	1.20
	Org. M (gkg^{-1})	47.80
	C/N Ratio	23:1
	Ca ($cmolkg^{-1}$)	1.20
	Mg ($cmolkg^{-1}$)	1.12
	Na ($cmolkg^{-1}$)	0.05
	K ($cmolkg^{-1}$)	0.17
	P ($mgkg^{-1}$)	4.26
	Zn ($mgkg^{-1}$)	5.90
	Mn ($mgkg^{-1}$)	2.45
	Cu ($mgkg^{-1}$)	1.70
	Fe ($mgkg^{-1}$)	170.4

The contents of organic matter and exchangeable magnesium were high compared to the critical values of 30 gkg^{-1} organic matter and 0.50 $cmolkg^{-1}$ Mg. The values of micronutrients in the soil;Zn, Mn, Cu and Fe were high compared to the critical values of 0.5 $mgkg^{-1}$ Zn, 1.0 $mgkg^{-1}$ Mn, 0.2 $mgkg^{-1}$ Cu and 4.5 $mgkg^{-1}$ Fe as reported by Ibia (2012) recommended for crop production in tropical soils. The inherent fertility status of the soil was low, therefore to obtain high yield of *Amaranthuscruentus* in the soil, organic amendment is highly recommended.

4.6 Initial weightsof the fresh compost treatments and weights of composts at 4 and 8 weeks after composting (WAC)

The weights of compostsat4 and 8 weeks after composting are presented in Table 6.

4.6.1 Initial weights of the fresh compost treatments

The initial weights of compost treatments on commencement of compostingweresignificantly higher than the weights at 4 and 8 WAC.The initial weight in SD/BCW (2.0 mm) 1:16 compost was not significantly ($P < 0.05$) different from the weights in SD/BCW (1.0 mm) 1:16 compost and SD/BCW (0.5 mm) 1:16 compost. These weights were not different from the weights in RH/BCW (2.0 mm) 1:16 compost, RH/BCW (1.0 mm) 1:16 compost and RH/BCW (0.5 mm) 1:16 compost. But theseweights were significantly higher than the weight in the remaining compost treatments. However, the weights of composts in some of the remaining compost treatments were not significantly different. The lowest weight was obtained in RH/BCW (0.5 mm) 1:1 compost which was not significantly different from the weights in RH/BCW (1.0 mm) 1:1 compost, RH/BCW (2.0 mm) 1:1 compost, SD/BCW (0.5 mm) 1:1 compost, SD/BCW (1.0 mm) 1:1 compost and SD/BCW (2.0 mm) 1:1 compost at commencement of composting.

4.6.2 Weights of compost treatments at 4 weeks after composting (WAC)

The weight of SD/BCW (2.0 mm) 1:1 compost was significantly ($P < 0.05$) higher than the weight in RH/BCW (2.0 mm) 1:1 compost at 4 WAC. The weight of RH/BCW (2.0 mm) 1:1 compost was not significantly different from the weight in RH/BCW (1.0 mm) 1:1 compost. These weights were significantly higher than the weights in the remaining compost treatments. However, the weights of composts in some of the remaining compost treatments were not significantly different. The lowest weight was obtained in RH/BCW (0.5 mm) 1:8 compost. The percent weight reduction in the composts at 4 weeks after composting ranged from 78 – 95%.

4.6.3 Weights of compost treatments at 8 weeks after composting (WAC)

The weight of SD/BCW (2.0 mm) 1:1 compost was significantly ($P < 0.05$) higher than the weight of RH/BCW (2.0 mm) 1:1 compost at 8 WAC. These weights were higher than the weight in RH/BCW (1.0 mm) 1:1 compost and this weight was higher than the weights in the rest of the compost treatments.

Nevertheless, the weights of composts in some of the remaining compost treatments were not significantly different. The least weight was obtained in RH/BCW (0.5 mm) 1:8 compost. The percent weight reduction in the compost treatments at 8 WAC ranged from 79 – 96%.

Generally, the percentweight reduction in compost with 0.5 mm particle size (92.0 %) was significantly ($P<0.05$) higher than the weight reduction in compost with 1.0 mm particle size (90.8%) but this weight reduction was not significantly differentfromthe weight reduction in compost with 2.0 mm particle size (90.2%) at 4 WAC.

TABLE 6

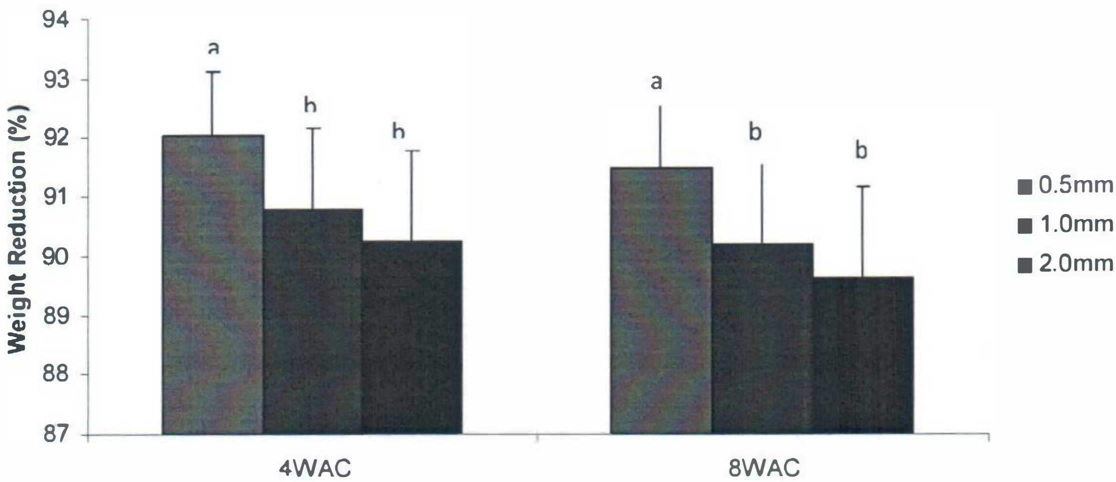
Initial weights (kg) of fresh compost treatments at 4 and 8 WAC

	4WAC			8WAC		
Treatment	Initial	Final	Weight loss (%)	Initial	Final	Weight loss (%)
RH/BCW 0.5 mm 1:1	876.3e	124.8f	-86	876.3e	117.3g	-87
RH/BCW 0.5 mm 1:4	1276.0d	104.5ijk	-92	1276.0d	96.4l	-92
RH/BCW 0.5 mm 1:8	1391.0c	64.2o	-95	1391.0c	60.6v	-96
RH/BCW 0.5 mm 1:16	1465.3a	115.7h	-92	1465.3a	105.5i	-93
RH/BCW 1.0 mm 1:1	877.5e	178.9bc	-80	877.5e	170.4c	-81
RH/BCW 1.0 mm 1:4	1276.8d	107.6i	-92	1276.8d	98.8k	-92
RH/BCW 1.0 mm 1:8	1393.5bc	77.8n	-94	1393.5bc	72.0u	-95
RH/BCW 1.0 mm 1:16	1461.8a	117.6gh	-92	1461.8a	110.6h	-92
RH/BCW 2.0 mm 1:1	876.0e	183.9b	-79	876.0e	176.7b	-80
RH/BCW 2.0 mm 1:4	1277.8d	114.7h	-91	1277.8d	105.0i	-92
RH/BCW 2.0 mm 1:8	1395.5bc	86.5m	-94	1395.5bc	78.9t	-94
RH/BCW 2.0 mm 1:16	1461.0a	106.5ij	-93	1461.0a	100.2j	-93
SD/BCW 0.5 mm 1:1	877.3e	161.9d	-82	877.3e	153.5e	-83
SD/BCW 0.5 mm 1:4	1273.0d	89.9lm	-93	1273.0d	84.5s	-93
SD/BCW 0.5 mm 1:8	1396.8bc	100.7jk	-93	1396.8bc	91.9p	-93
SD/BCW 0.5 mm 1:16	1459.8a	93.7l	-94	1459.8a	88.5r	-94
SD/BCW 1.0 mm 1:1	874.0e	174.2c	-80	874.0e	168.8d	-81
SD/BCW 1.0 mm 1:4	1277.8d	105.3ijk	-92	1277.8d	95.6m	-93
SD/BCW 1.0 mm 1:8	1397.5bc	99.8k	-93	1397.5bc	90.4q	-94
SD/BCW 1.0 mm 1:16	1461.0a	123.3fg	-92	1461.0a	117.0g	-92
SD/BCW 2.0 mm 1:1	876.0e	195.1a	-78	876.0e	187.9a	-79
SD/BCW 2.0 mm 1:4	1277.8d	103.7ijk	-92	1277.8d	94.0o	-93
SD/BCW 2.0 mm 1:8	1395.5bc	102.4ijk	-93	1395.5bc	94.8n	-93
SD/BCW 2.0 mm 1:16	1460.5a	146.6e	-90	1460.5a	140.8f	-90

Mean with the same superscript along the same column are not significantly different ($p < 0.05$

Similarly,the percent weight reduction in 0.5 mm compost (91.5%) was significantly higher than the percent weight reduction in 1.0 mm compost (90.2%) but this was not significantly differentfrom the percent weight reduction in 2.0 mm compost (89.6%) at 8 WAC(Figure 2).The initial weights of the compostson commencement of compostingincreased as the composting ratiosincreases (Figure 3). The percent weight reduction in RH/BCW (0.5 mm) compost (91.9%) was significantly ($P<0.05$) higher than percent weight reduction in RH/BCW (1.0 mm) compost (90.0%) but this was not different from the percent reduction in RH/BCW (2.0 mm) compost (89.9%) at 4 WAC. Similarly, the percent weight reduction in SD/BCW (0.5 mm) compost (90.8%) was significantly ($P<0.05$) higher than percent weight reduction in SD/BCW (1.0 mm) compost (89.7%) but this was not different from percent reduction in SD/BCW (2.0 mm) compost (88.7%)at 4 WAC (Figure 4). The percent weight reduction was significantly ($P<0.05$) higher in RH/BCW (0.5 mm) compost (91.3%) than percent weight reduction in RH/BCW (1.0 mm) compost (89.4%) but this was not different from percent weight reduction in RH/BCW (2.0 mm) compost (89.1%).

Similarly, the percent reduction in SD/BCW (0.5 mm) compost (90.2%) was significantly higher than the reduction in SD/BCW (1.0 mm) compost (89.1%) but this weight was not different from the weight in SD/BCW (2.0 mm) compost (88.1%) (Figure 5). The percent weight reductions recorded in the various compost treatments was earlier reported by Chen *et al.* (1992) and John *et al.* (1996) who observed that composting enhance 50% reduction in mass and volume of composted materials.



Particle sizes

FIG. 2: Particle sizes of compost treatments on the percent weight reduction in composts at 4 and 8 WAC

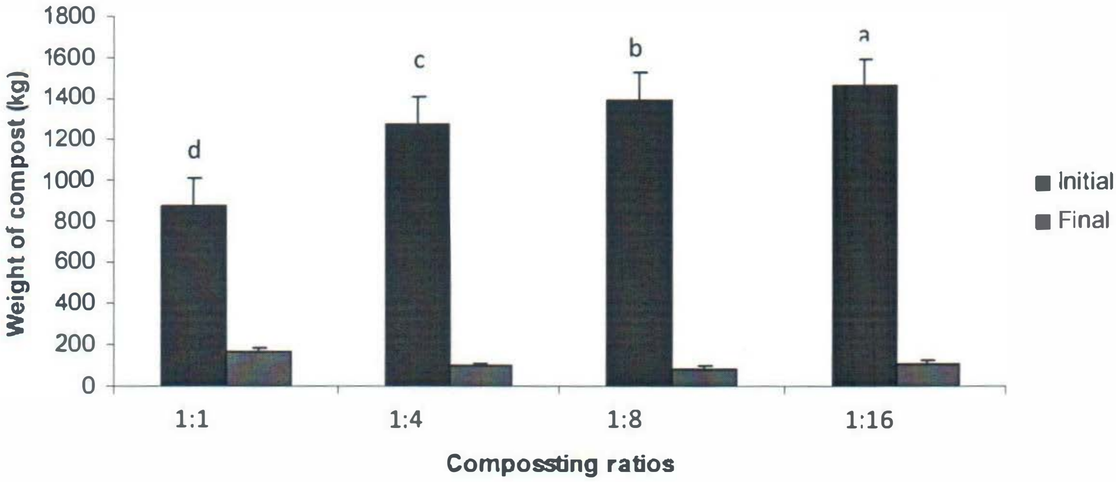
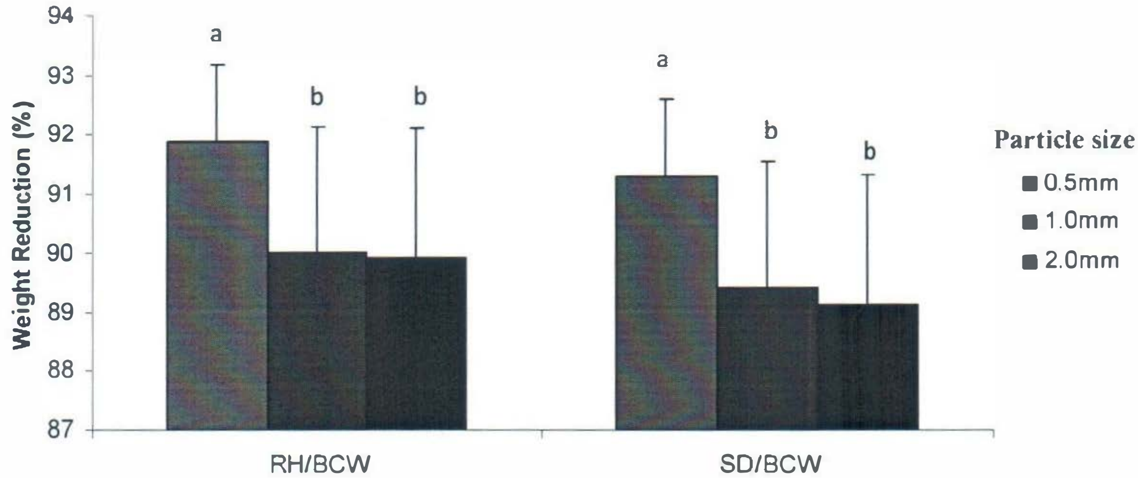


FIG.3: Initial weights of compost treatments on commencement of compostingand at 8 WAC as affected by composting ratios



Compost treatment

FIG. 4:Particle sizes of RH/BCW and SD/BCW composts on percent weight reductionat 4 WAC.

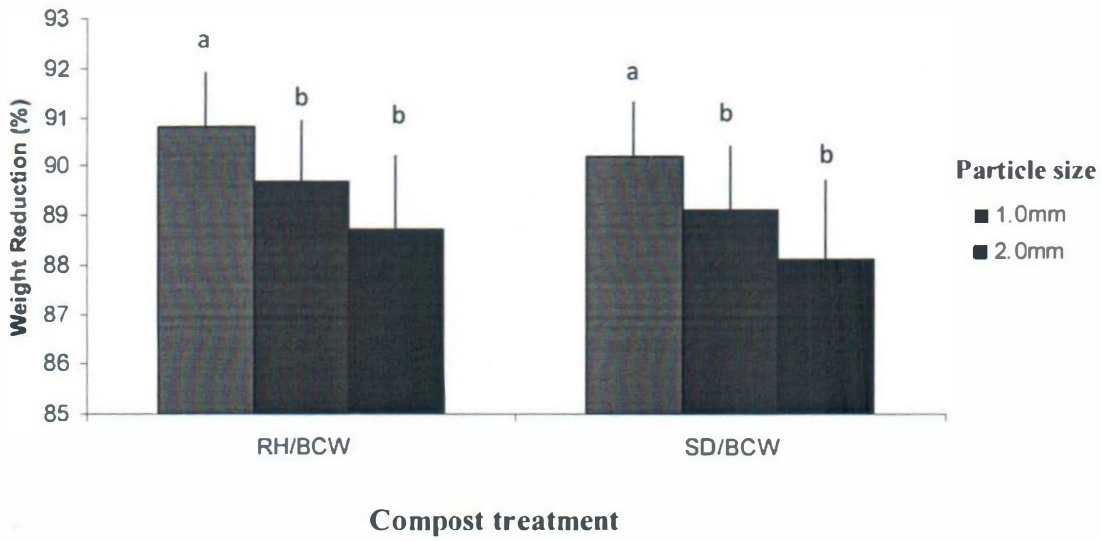


FIG. 5:Particle sizes of RH/BCW and SD/BCW composts on percent weight reduction at 8 WAC.

4.7. Composts temperatures

The compost temperatures before (T1) and afterturning (T2)and the ambient temperature (T0) measured throughout the composting period are presented in Table 7. The influence of composttypes, particle sizes and composting ratios oncompost temperaturesare shown in Figures 6, 7and8.Specifically, SD/BCW (2.0 mm)1:16 compost had the highest temperature(56.3°C) at three days after composting.The maximum temperature (60.8 °C) was obtained in SD/BCW (0.5 mm) 1:16 compost at 6 days after composting. This increase in temperature within the first two turnings was observed by John and Ijah(2012) who reported a sharp increase in cattle dung/poultry manure compost temperature from 43 to 47 °C during the first two turnings and then increased gradually during the second week. They added that the temperature stabilized at third week after which it began to drop to near ambient temperature at the end of the composting. The maximum temperature recorded in compost with 0.5 mm particle size was reported by Insam and De-Bertoldi (2007) and attributed that to the available surface area of organic materials for higher rate of decomposition of the materials by microorganisms because most of the activity occurs at the interface of particle size. Mina *et al.* (2012) reported a maximum temperature of 49 °C for compost with particle size of 10 - 20 mm at 14 days of composting.

The compost temperatures declined within twelve days of composting.At two weeks after composting the compost temperature declined to 53 °C in SD/BCW (2.0 mm) 1:16 compost. The compost temperatures of somecompost windrows gradually reduced at two weeksafter composting throughout the remaining period of composting until the compost temperatures were at the ambient temperature (30°C) at seventy two days after composting.

TABLE 7

Compost and ambient temperature(^{o}C)fluctuations during the compostingperiod

Treatment	Day 3		Day 6		Day 9		Day 12		Day 15		Day 30		Day 44	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
RH/BCW 0.5 (1:1)	50.8de	36.8cde	46.8h	35.8defg	45.8e	35.8bcde	42.8ef	35.8ab	46.8gh	35.75cdef	47.75a	35.75abcd	38.75f	34.75bcde
RH/BCW 0.5(1:4)	47.3hi	35.3fgh	44.3i	35.3defg	42.3gh	35.3bcde	40.3hij	35.3abc	43.3klm	34.25g	44.25fghi	34.25ef	40.25de	35.25abcd
RH/BCW 0.5 (1:8)	45.8j	35.8efg	43.8i	34.8fg	42.8g	33.8g	40.8hi	33.8d	44.8ij	34.75efg	45.75bcde	35.75abcd	41.75bc	34.75bcde
RH/BCW 0.5(1:16)	44.3kl	34.3h	41.3j	35.3defg	39.3i	34.3fg	37.3l	34.3cd	41.3o	35.25defg	44.25fghi	34.25ef	42.25ab	35.25abcd
RH/BCW 1.0(1:1)	50.5def	36.5cdef	46.5h	36.5cd	45.5ef	36.5ab	42.5efg	35.5abc	45.5hi	36.5bcd	46.5abc	36.5a	40.5cd	36.5a
RH/BCW 1.0(1:4)	47.5h	35.5efgh	44.5i	35.5defg	41.5gh	34.5efg	38.5kl	34.5bcd	41.5no	34.5fg	43.5hi	34.5def	39.5def	34.5cdef
RH/BCW 1.0(1:8)	45.5jk	35.5efgh	44.5i	35.5defg	42.5g	34.5efg	41.5gh	34.5bcd	44.5ijk	35.5cdefg	45.5bcdef	35.5abcde	43.5a	35.5abcd
RH/BCW 1.0(1:16)	43.5l	34.5gh	41.5j	34.5g	39.5i	34.5efg	38.5kl	34.5bcd	42.5mno	35.5cdefg	45.5bcdef	35.5abcde	43.5a	35.5abcd
RH/BCW 2.0(1:1)	51.8cd	37.8bc	47.8fgh	35.8defg	46.8cde	35.8bcde	43.8cde	34.8bcd	48.8ef	35.75cdef	46.75ab	35.75abcd	40.75cd	35.75abc
RH/BCW 2.0(1:4)	49.0g	36.0def	45.0i	36.0cdef	41.0h	35.0cdef	39.0jk	35.0abcd	43.0lm	36bcde	45defg	35bcdef	39ef	35bcde
RH/BCW 2.0(1:8)	45.8j	35.8efg	43.8i	34.8fg	42.8g	33.8g	39.8ijk	33.8d	42.8mn	35.75cdef	44.75efgh	34.75cdef	41.75bc	34.75bcde
RH/BCW 2.0 (1:16)	46.0ij	36.0def	44.0i	35.0efg	41.0h	36.0abcd	39.0jk	35.0abcd	44.0ijl	36bcde	46bcde	36abc	43ab	36ab
SD/BCW 0.5 (1:1)	51.3cde	37.3bcd	48.3efg	35.3defg	46.3de	35.3bcde	43.3de	34.3cd	50.3cd	36.25bcd	45.25cdef	35.25abcde	38.25f	34.25def
SD/BCW 0.5 (1:4)	50.8de	36.8cde	48.8ef	34.8fg	46.8cde	34.8def	44.8b	34.8bcd	47.8fg	34.75efg	41.75j	33.75f	35.75g	33.75ef
SD/BCW 0.5(1:8)	53.3b	37.3cd	51.3c	37.3bc	48.3b	35.3bcde	45.3b	35.3abc	49.3dc	36.25bc	44.25fghi	34.25ef	35.25g	33.25f
SD/BCW 0.5(1:16)	51.8de	36.8cde	60.8a	39.8a	47.8bc	34.8def	44.8b	34.8bcd	50.8c	36.75bc	43.75ghi	33.75f	35.75g	33.75ef
SD/BCW 1.0(1:1)	51.3cde	37.3bcd	49.3de	36.3cde	48.3b	36.3abc	45.3b	35.3abc	50.3cd	36.25defg	45.25cdef	36.25ab	38.25f	35.25abcd
SD/BCW 1.0(1:4)	50.3efg	36.3def	49.3de	35.3defg	48.3b	35.3bcde	45.3b	35.3abc	49.3dc	35.25defg	43.25i	34.25ef	36.25g	34.25def
SD/BCW 1.0 (1:8)	53.3b	38.3ab	50.3cd	37.3bc	47.3bcd	36.3abc	44.3de	35.3abc	48.3ef	36.25bcd	43.25i	35.25abcde	36.25g	34.25def
SD/BCW 1.0(1:16)	53.3b	37.3bcd	51.3c	37.3bc	48.3b	35.3bcde	44.3de	34.3cd	52.3ab	37.25ab	45.25cdef	35.25abcde	36.25g	34.25def
SD/BCW 2.0(1:1)	49.3fg	35.3fgh	47.3gh	35.3defg	44.3f	35.3bcde	41.3gh	34.3cd	49.3dc	35.25defg	45.25cdef	35.25abcde	36.25g	34.25def
SD/BCW 2.0(1:4)	52.3bc	38.3ab	50.3cd	37.3bc	48.3b	36.3abc	47.3a	36.3a	51.3bc	36.25bcd	45.25cdef	35.25abcde	38.25f	35.25abcd
SD/BCW 2.0(1:8)	52.3bc	37.3bcd	50.3cd	36.3cde	47.3bcd	35.3bcde	44.3de	34.3cd	48.3ef	35.25defg	43.25i	34.25abcde	35.25g	33.25f
SD/BCW 2.0(1:16)	56.3a	39.3a	53.3b	38.3b	50.3a	37.3a	47.3a	36.3a	53.3a	38.25a	46.3abc	36.25ab	38.25f	35.25abcd
Ambient temperature	30m	30i	30k	30h	31j	31h	30m	30e	31p	31h	32k	32g	32h	32g

Mean with the same superscript along the same column are not significantly different ($p<0.05$)

TABLE 7 contd

Treatment	Day 58		Day 72	
	T1	T2	T1	T2
RH/BCW 0.5(1:1)	35.75de	34.75ab	33.75ab	32.75abc
RH/BCW 0.5(1:4)	34.25fgh	33.25cde	32.25cdef	32.25abcd
RH/BCW 0.5(1:8)	36.75cd	34.75ab	32.75bcde	32.75abc
RH/BCW 0.5(1:16)	38.25ab	34.25abc	32.25cdef	32.25abcd
RH/BCW 1.0(1:1)	37.5bc	35.5a	33.5abc	33.5a
RH/BCW 1.0 (1:4)	35.5def	34.5abc	32.5bcdef	32.5abcd
RH/BCW 1.0(1:8)	38.5ab	35.5a	34.5a	33.5a
RH/BCW 1.0(1:16)	39.5a	34.5abc	32.5bcdef	32.5abcd
RH/BCW 2.0(1:1)	36.75bc	34.75ab	33.75ab	32.75abc
RH/BCW 2.0(1:4)	34ghi	34bcd	33bcde	33abc
RH/BCW 2.0(1:8)	35.75de	34.75ab	31.75efg	31.75cde
RH/BCW 2.0(1:16)	38bc	35ab	32defg	32bcde
SD/BCW 0.5 (1:1)	34.25fgh	34.25abc	31.25fg	31.25de
SD/BCW 0.5(1:4)	32.75ij	32.75de	30.75g	30.75e
SD/BCW 0.5(1:8)	33.25hij	33.25cde	31.25fg	31.25de
SD/BCW 0.5(1:16)	32.75ij	32.75de	31.75efg	31.75cde
SD/BCW 1.0 (1:1)	34.25fgh	34.25abc	32.25cdef	32.25abcd
SD/BCW 1.0 (1:4)	32.25j	32.25e	31.25fg	31.25de
SD/BCW 1.0(1:8)	34.25fgh	34.25abc	32.25cdef	32.25abcd
SD/BCW 1.0(1:16)	34.25fgh	33.25cde	32.25cdef	32.25abcd
SD/BCW 2.0(1:1)	33.25hij	33.25cde	31.25fg	31.25de
SD/BCW 2.0(1:4)	35.25efg	34.25abc	33.25abcd	33.25ab
SD/BCW 2.0(1:8)	33.25hij	33.25cde	32.25cdef	32.25abcd
SD/BCW 2.0(1:16)	34.25fgh	34.25abc	32.25cdef	32.25abcd
Ambient temperature	31k	31f	30h	30f

Mean with the same superscript along the same column are not significantly different ($p<0.05$)

Three (3) days after composting, the temperature value before turning was significantly ($P < 0.05$) higher in SD/BCW (2.0 mm) 1:16 compost than in SD/BCW (1.0 mm) 1:16 compost. Compost temperature in SD/BCW (1.0 mm) 1:16 compost was not significantly different from the temperature values in SD/BCW (1.0 mm) 1:8 compost, SD/BCW (0.5 mm) 1:8 compost, SD/BCW (2.0 mm) 1:8 compost and SD/BCW (2.0 mm) 1:4 compost. These temperature values were significantly ($P < 0.05$) higher than the temperature values in the remaining compost treatments. The lowest temperature value was obtained in RH/BCW (1.0 mm) 1:16 compost at 3 days after composting.

Six (6) days after composting, the temperature value in SD/BCW (0.5 mm) 1:16 compost was significantly ($P<0.05$) higher than the value obtained in SD/BCW (2.0 mm) 1:16 compost. The temperature values in the listed composts were higher than the value in the remaining compost treatments. However, the values in some of the remaining compost treatments were not significantly different. The least value was obtained in RH/BCW (1.0 mm) 1:16 compost at 6 days after composting.

Nine (9) days after composting, the compost temperature before turning was significantly ($P<0.05$) higher in SD/BCW (2.0 mm) 1:16 compost than in SD/BCW (2.0 mm) 1:4 compost. The compost temperature in SD/BCW (2.0 mm) 1:4 compost was not significantly different from the values in SD/BCW (1.0 mm) 1:16 compost, SD/BCW (1.0 mm) 1:4 compost, SD/BCW (1.0 mm) 1:1 compost and SD/BCW (0.5 mm) 1:8 compost. These were not significantly different from the temperature values in SD/BCW (2.0 mm) 1:8 compost, SD/BCW (1.0 mm) 1:8 compost and SD/BCW (0.5 mm) 1:16 compost. But these values were significantly ($P < 0.05$) higher than the values obtained in the remaining compost treatments. The lowesttemperature value was obtained in RH/BCW (0.5 mm) 1:16 compost which was not significantly different from the value in RH/BCW (1.0 mm) 1:16 compost.

Twelve(12) days after composting, the compost temperature in SD/BCW (2.0 mm) 1:16 compost was not significantly ($P<0.05$) different from the value in SD/BCW (2.0 mm) 1:4 compost.These values were significantly higher than the temperature values in the rest of the compost treatments. The least value was obtained in RH/BCW (0.5 mm) 1:16 compost at 12 days after composting.

Fifteen(15) days after composting, the temperature in SD/BCW (2.0 mm) 1:16 compost was not significantly ($P<0.05$) differentfrom the value of SD/BCW (1.0 mm) 1:16 compost.But thesevalues were significantly higher than the values obtained in other compost treatments. The lowest value was obtained in RH/BCW (0.5 mm) 1:16 compost at 15 days after composting.

Thirty(30) days after composting, the temperature values before turning werenot significantly ($P<0.05$) different in RH/BCW (0.5 mm) 1:1 compost, RH/BCW (1.0 mm) 1:1 compost, RH/BCW (2.0 mm) 1:1 compost and SD/BCW (2.0 mm) 1:16 compost.These values were significantly higher than valuesobtained in the remaining compost treatments. The lowest value was obtained in SD/BCW (0.5 mm) 1:4 compost at 30 days after composting.

Forty four(44) days after composting, the temperature values were not significantly ($P<0.05$) different in RH/BCW (1.0 mm) 1:8 compost, RH/BCW (1.0 mm) 1:16

compost, RH/BCW (2.0 mm) 1:16 compost and RH/BCW (0.5 mm) 1:16 compost. However, these values were higher than the values in rest of the compost treatments. The lowest values were obtained in SD/BCW (1.0 mm) 1:4 compost, SD/BCW (1.0 mm) 1:8 compost, SD/BCW (1.0 mm) 1:16 compost, SD/BCW (2.0 mm) 1:1 compost and SD/BCW (2.0 mm) 1:8 compost at 44 days after composting.

Fifty eight(58) days after composting, the compost temperatures before turning werenot significantly ($P<0.05$) different inRH/BCW (1.0 mm) 1:16 compostand RH/BCW (1.0 mm) 1:8 compost.These values were not also different from the value obtained in RH/BCW (0.5 mm) 1:16 compost.But thesevalues were significantly higher than the values in the remaining compost treatments. The lowest value was obtained in SD/BCW (1.0 mm) 1:4 compost at 58 days after composting.

Seventy two(72) days after composting, the compost temperatures before turning werenot significantly ($P<0.05$) different in RH/BCW (1.0 mm) 1:8 compost, RH/BCW (0.5 mm) 1:1 compost, RH/BCW (1.0 mm) 1:1 compost, RH/BCW (2.0 mm) 1:1 compost and SD/BCW (2.0 mm) 1:4 compost. These were higher than the temperature valuesin the remaining compost treatments.The least value was obtained in SD/BCW (0.5 mm) 1:4 compost at 72 days after composting.

The compost temperature before turning was significantly ($P<0.05$) higher in SD/BCW composts than in RH/BCW composts (Figure 6). The temperature variation in the compost windrows is assumed to be a factor of substrate availability and the strains of microorganisms that worked on the materials during decomposition process.The compost temperature before turning (T1)was significantly ($P<0.05$)

higher in composts with 2.0 mm particle size than in composts with 1.0 mm particle size which in turn was significantly higher than the temperature in composts with 0.5 mm particle size (Figure 7). The compost temperaturebefore turning was significantly ($P < 0.05$) higher in compost prepared in 1:1 composting ratio which was significantly higher than the temperature incompost prepared in 1:16 composting ratio and its value was higher than that in compost prepared in 1:8 composting ratiowhich in turn was significantly higher than the value in compost prepared in 1:4 composting ratio (Figure 8). The 1:1 compost ratios contained equal dry weight of rice husk or sawdust and poultry manure which must have supplied adequate amount of substrates for microbial decomposition and therefore increased the compost temperature due to increased rate of decomposition in the heaps that contained such material. Compost temperatures also increased as the amount of poultry manure in each compost heap increases.

4.8 Microorganisms detected in the prepared composts at 8 weeks after composting (WAC)

The total bacteria, actinomycetes and fungi counts in the prepared composts at 8 WACare presented in Table 8.

The total bacteria count in the prepared composts at 8 WAC was significantly ($P<0.05$) higherin RH/BCW (1.0 mm)1:4 compost thanin RH/BCW (1.0 mm) 1:8 compost.The bacteria count in RH/BCW (1.0 mm) 1:8 compost was significantly ($P < 0.05$) higher than the count in RH/BCW (1.0 mm)1:16 compost and this was also higher than the count in the remaining compost treatments. The lowest bacteria count was obtained in RH/BCW (2.0 mm) 1:16 compost.

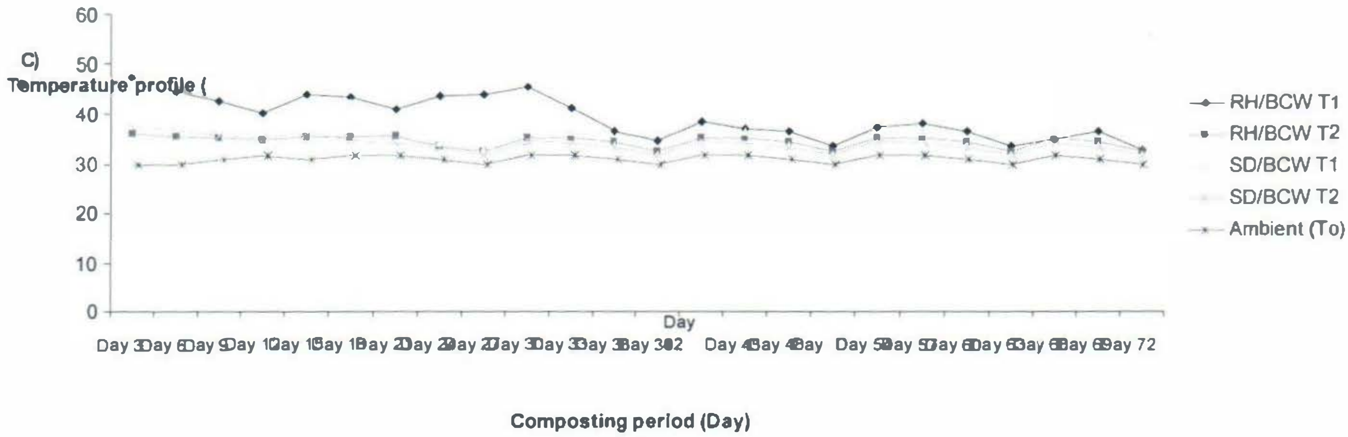


FIG. 6: Effects of compost types on temperatures throughout thecomposting process

LEGEND:
SD/BCW (T1) a
RH/BCW (T1) b
Ambient (T0) c

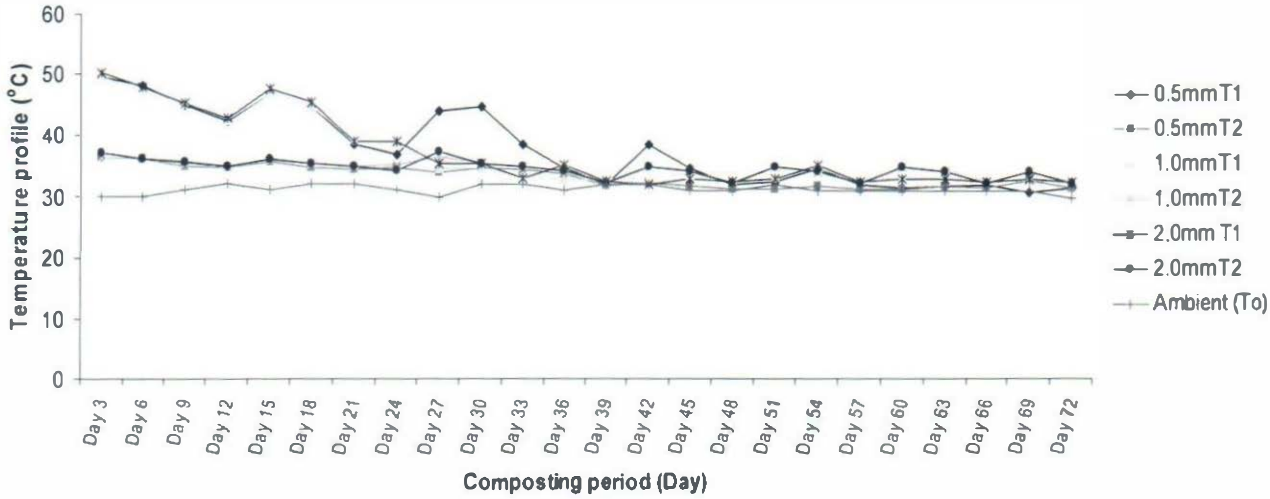


FIG.7: Effects of various particle sizes on temperature throughout the compostingprocess

LEGEND:
2.0 mm (T1) a
1.0 mm (T1) b
0.5 mm (T1) c
Ambient (T0) d

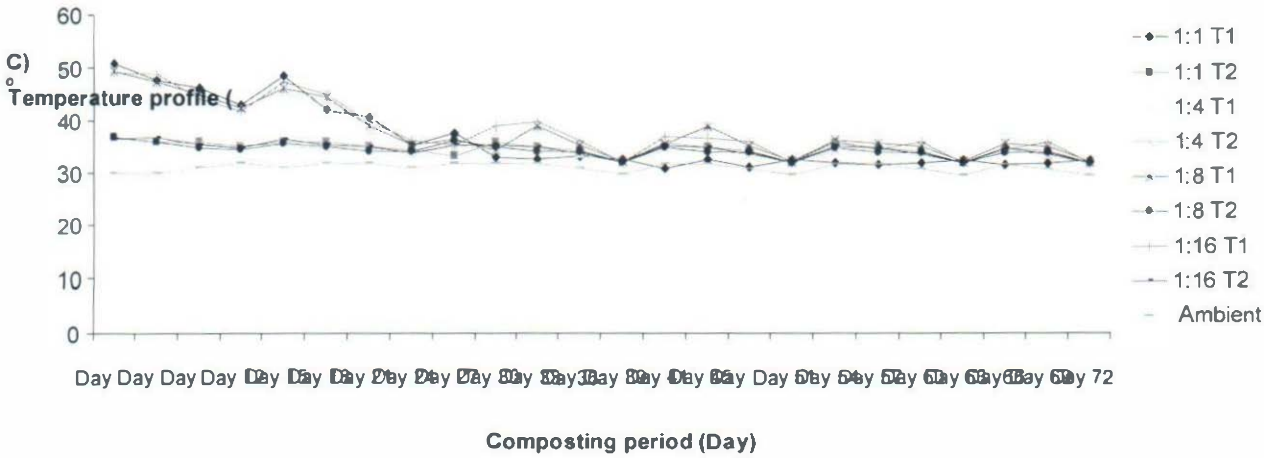


FIG. 8: Effects of composting ratios on temperaturethroughout the composting process

LEGEND:
1:1 (T1) a
1:16 (T1) b
1:8 (T1) c
1:4 (T1) d
Ambient (T0) e

The total fungi count in RH/BCW (0.5 mm)1:4 compost at 8 WAC was significantly ($P<0.05$) higher thanits count in RH/BCW (2.0 mm) 1:1 compost.Fungi count reduced by 50% in RH/BCW (0.5 mm) 1:4 compost and 69% in RH/BCW (2.0 mm) 1:1 compost than the bacteria count at 8 WAC. Fungi count in RH/BCW (2.0 mm) 1:1 compost was significantly ($P < 0.05$) higher than its count in the remaining compost treatments with different percent reductions from the bacteria counts. The least fungi count was obtained in SD/BCW (2.0 mm) 1:4 compost with 97% count reduction compared with bacteria count at 8 WAC.

Total actinomycetes count in SD/BCW (0.5 mm) 1:4 compost was significantly ($P < 0.05$) higher than the count in SD/BCW (1.0 mm) 1:1 compost. This was significantly higher than actinomycetes count in SD/BCW (2.0 mm) 1:4 compost.

The total bacteria counts in the compost treatments ranged from 2.8×10^{-7} in RH/BCW(2.0 mm) 1:16compost to 20.25×10^{-7}(cfu/g) in RH/BCW(1.0 mm)1:4 compost. Actinomycetes were found in SD/BCW (2.0 mm) 1:4 compost, SD/BCW (1.0 mm) 1:1 compost and SD/BCW (0.5 mm) 1:4 compost. Actinomycetes counts ranged from 0.98×10^{-7}in SD/BCW (2.0 mm) 1:4 compost to 1.402×10^{-7} (cfu/g) in SD/BCW (0.5 mm) 1:4 compost. The total fungi counts in the composts ranged from 0.255×10^{-7} in SD/BCW (2.0 mm)1:4 compost to 4.625×10^{-7}(cfu/g) in RH/BCW (0.5 mm)1:4 compost. The total bacteria counts were significantly higher in RH/BCW composts than the total fungi counts. However, actinomycetes were not found in RH/BCW composts. The total bacteria counts were also higher in SD/BCW composts than total fungi counts. The total fungi counts in SD/BCW composts were significantly higher than the actinomycetes counts (Figure 9).

TABLE 8

Prevalence contents of Bacteria, Fungi and Actinomycete in the different compost treatments at 8 WAC.

Treatment	Bacteria ($x10^{-7}$cfu/g)	Fungi ($x10^{-7}$cfu/g)	Actinomycetes ($x10^{-7}$cfu/g)
RH/BCW 0.5 mm 1:1	10.925i	2.225h	-
RH/BCW 0.5 mm 1:4	9.225k	4.625a	-
RH/BCW 0.5 mm 1:8	6.725q	1.325k	-
RH/BCW 0.5 mm 1:16	10.275j	3.975c	-
RH/BCW 1.0 mm 1:1	9.275k	3.95c	-
RH/BCW 1.0 mm 1:4	20.25a	2.175h	-
RH/BCW 1.0 mm 1:8	19.875b	3.075e	-
RH/BCW 1.0 mm 1:16	18.825c	0.315lm	-
RH/BCW 2.0 mm 1:1	13.825e	4.225b	-
RH/BCW 2.0 mm 1:4	13.625f	3.025e	-
RH/BCW 2.0 mm 1:8	10.85i	0.33lm	-
RH/BCW 2.0 mm 1:16	2.8t	0.37lm	-
SD/BCW 0.5 mm 1:1	7.725n	0.305lm	-
SD/BCW 0.5 mm 1:4	10.923i	1.725j	1.402a
SD/BCW 0.5 mm 1:8	8.625l	0.265lm	-
SD/BCW 0.5 mm 1:16	6.875p	2.375g	-
SD/BCW 1.0 mm 1:1	4.73r	0.4l	1.220b
SD/BCW 1.0 mm 1:4	12.175gh	2.475f	-
SD/BCW 1.0 mm 1:8	4.575s	2.775f	-
SD/BCW 1.0 mm 1:16	8.325m	3.325d	-
SD/BCW 2.0 mm 1:1	7.225o	0.385lm	-
SD/BCW 2.0 mm 1:4	7.345o	0.255m	0.980c
SD/BCW 2.0 mm 1:8	14.85d	1.65j	-
SD/BCW 2.0 mm 1:16	12.2gh	2i	-

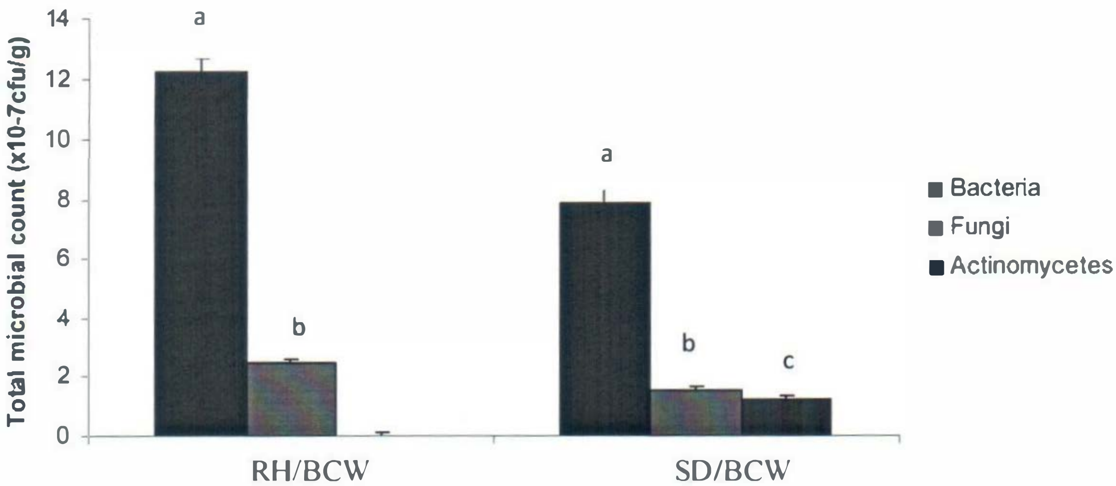
Mean with the same superscript along the same column are not significantly different ($p<0.05$)

The total bacteria countsin 0.5 mm particle size composts were significantly (P<0.05) higher than total fungi counts. The total fungi counts in 0.5 mm particle size composts were higher than the total actinomycetes counts. Moreover, the total bacteria counts in 1.0 mm particle size composts were significantly (P<0.05) higher than total fungi counts. The total fungi counts in 1.0 mm particle size composts were higher than the total actinomycetes counts. Total bacteria counts in 2.0 mm particle size composts were significantly (P<0.05) higher than total fungi counts. Total fungi counts in 2.0 mm particle size composts were higher than actinomycetes counts (Figure 10).

Total bacteria counts were significantly higher in 1:1 composts than the total fungi counts. The total fungi counts were higher in 1:1 composts than the actinomycetes counts. The total bacteria counts were significantly higher in 1:4 composts than the total fungi counts. Total fungi counts were higher in 1:4 composts than the actinomycetes counts. Total bacteria counts were significantly higher in 1:8 composts than the total fungi counts.

Actinomycetes were not detected in 1:8 composts at 8 WAC. Total bacteria counts were significantly higher in 1:16 composts than the total fungi counts. Acctinomycetes were not found in 1:16 composts at 8 WAC (Figure 11).

Eight species of bacteria and their percentage incidences were detected in the compostsin the order;*Bacillus sp.*(32.9%), *Xanthomonas sp.*(21.4%),*Staphylococcus aureus*(15.7%),*Pseudomonas sp.* (10.0%),*Bacillus subtilis* (7.1%), *Micrococcus sp.* (4.3%), *Staphylococcus epidermidis* (2.9%) and *Serratia sp.* (1.4%). Only one species of actinomycetes(*Actinomyces sp.)*was detected in SD/BCW composts and its percentage incidence was4.3%. Nine species of fungi and their percentage incidences were detected in the various compost treatments in the order; *Mould sp.* (25.7%), *Penicillium sp.* (20.3%),*Yeast sp.* (14.9%), *Trichoderma sp.* (13.5%), *Aspergillus*



Compost type

FIG. 9: Effects of compost types on total microbial counts at 8WAC

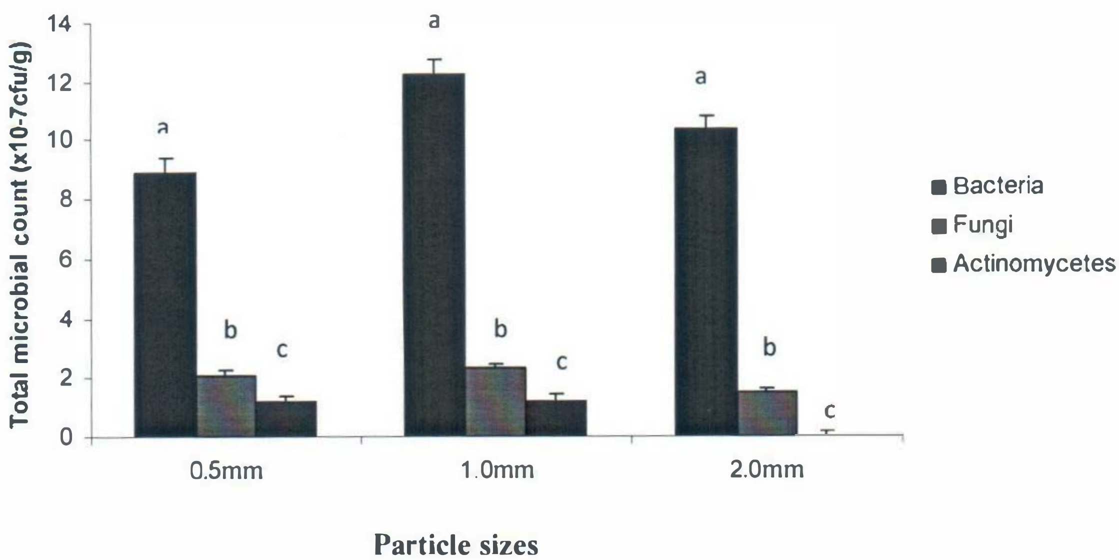


FIG.10: Effects of particle sizes of composts on total microbial counts at 8 WAC

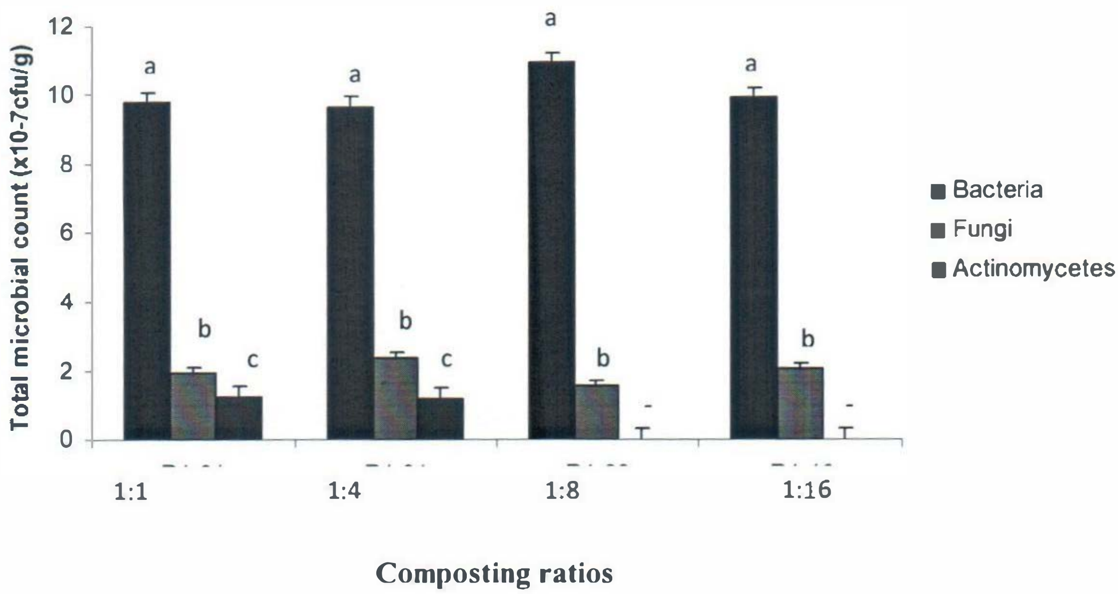


FIG. 11: Effects of composting ratios of different organic waste on total microbial counts at 8 WAC

flavus (8.1%), *A. carbonaceous* (8.1%),*Aspergillus niger* (4.0%), *A. fumigatus* (2.7%) and *Scopulariopsis sp.* (2.7%) (Appendices 1 and 2).The percentage incidence of bacteria ranged from 1.4 to 32.9%. *Bacillus sp* (32.9%) was higher than*Xanthomonas sp* (21.4%) while *Serratia sp* (1.4%) had the lowest percentage incidence. The percentage incidence of fungi ranged from 2.7 to 25.7%where *Mould sp* (25.7%) had the highest incidence in the composts followed by *Penicillium sp* (20.3%) while*Scopulariopsis sp.*and*Aspergillus fumigatus* recorded the lowest (2.7%) incidence in the composts.

The total microbial counts in the composts revealed a higher number of bacteria than the fungi and few counts of actinomycetes. The highest bacteria species isolated in the composts was the *Bacillus spp.* found in almostall the compostheaps except in RH/BCW (1:16) 0.5 mm and this confirm the findings of Neher (2013) who reported that bacteria are very important microbial populations that exist throughout the composting period.The highest fungi speciesdetected in the composts was the *Mould spp.* found in nineteen compost treatments but not in this five treatments.

The total bacteria countswas significantly higher in RH/BCW composts than in SD/BCW composts which may be attributed to highavailability of substrates in RH/BCW compoststhan in SD/BCW composts. This phenomenon may also be attributed to the assertion that bacteria can thrive wellwithin temperature range of 30 – 50°C whereas fungi can grow well at temperature above the range suitable for bacteria.This observation is in line with the findings of Wolna-Maruwka *et. al.* (2009) who indicated that temperature increase in the composted materials led to a drop in the proliferation of fungi and also stated that a successive factor resulting in the decrease of fungi number could be the increase of pH in the composted materials.

4.9 Effects of compost treatments on growth of *Amaranthuscruentus* at 2, 4, 6 and 8 weeks after transplanting (WAT) in 2016 and 2017 planting seasons

The effects of different compost treatments on *Amaranthus cruentus* height at 4, 6 and 8 weeks after transplanting (WAT) in 2016 and 2017 cropping seasons are presented in Table 9.The seedlings were transplanted at average height of 2 cm in both seasons at 2 weeks after sowing.

4.9.1 *Amaranthus* height (cm) at 4 weeks after transplanting (WAT) in 2016 cropping season as influenced by different compost treatments.

In 2016 season at 4 weeks after transplanting (WAT), *Amaranthus* height was significantly($P<0.05$)higher in plot treated withRH/BCW (0.5 mm) 1:16 compostthan in plottreated with SD/BCW (1.0 mm) 1:16 compos.This height was not significantly different from the height measured in plot treated with SD/BCW (2.0 mm) 1:1 compost.

However, *Amaranthus* height measured in plot treated with SD/BCW (2.0 mm) 1:1 compost was significantly ($P < 0.05$) higher than heights obtained in plots fertilized with the remaining compost treatments. However, the plant heights in some of the remaining treated plots were not significantly different. The lowest plant height was obtained in the control at 4 WAT. *Amaranthus* heights at 4 weeks after transplanting (WAT) are shown on Plate 2.

4.9.2 Effects of compost treatments on *Amaranthus* height (cm) at 6 WAT in 2016 cropping season.

In 2016 season at 6weeks after transplanting (WAT), *Amaranthus* height was significantly($P<0.05$)higher in plot treated withRH/BCW (0.5 mm) 1:16 compostthan in plottreated with SD/BCW (2.0 mm) 1:16 compost. These compost treatments recorded significantly ($P < 0.05$) higher plant height than the height measured in plot

TABLE 9

Effects of compost treatments on plant height of *Amaranthuscruentus*in 2016and 2017 planting seasons

Plant height (cm)						
		(2016)			(2017)	
Treatment	**4WAT**	**6WAT**	**8WAT**	**4WAT**	**6WAT**	**8WAT**
RH/BCW 0.5 mm 1:1	21.325f	43.725f	72.425bc	23.575ij	32.825mn	43.825m
RH/BCW 0.5 mm 1:4	13.53m	31.4o	42.57o	22.65l	43.15d	62.2d
RH/BCW 0.5 mm 1:8	17.4j	39.1jk	68.73f	30.4b	52.4a	72.4a
RH/BCW 0.5 mm 1:16	27.755a	54.425a	74.125a	26.625e	38.375i	56.925f
RH/BCW 1.0 mm 1:1	24.05c	49.35c	72.55b	19.45n	27.95p	41.25n
RH/BCW 1.0 mm 1:4	16.115k	27.775p	47.725m	27.975d	41.725f	55.475g
RH/BCW 1.0 mm 1:8	17.15j	36.15m	57.65j	27.65d	47.4b	61.65d
RH/BCW 1.0 mm 1:16	21.525f	39.775i	59.025i	32.275a	52.275a	69.775b
RH/BCW 2.0 mm 1:1	19.2i	46e	69.8e	23.3jk	35.3k	54.1h
RH/BCW 2.0 mm 1:4	20.375h	36.075m	46.825n	28.825c	40.575g	57.375f
RH/BCW 2.0 mm 1:8	18.73i	39.55ijk	70.52d	28.6c	44.35c	59.15e
RH/BCW 2.0 mm 1:16	20.45h	39.7ij	62.95g	26.2ef	39.45h	53.7h
SD/BCW 0.5 mm 1:1	18.615i	41.325gh	59.225i	21.325m	28.825o	41.825n
SD/BCW 0.5 mm 1:4	23.3d	46.6de	63.15g	26.4l	41.65f	46.4k
SD/BCW 0.5 mm 1:8	20.57gh	43.7f	59.15i	22.65l	29.4o	39.7p
SD/BCW 0.5 mm 1:16	22.625e	41.925g	71.875c	20.875m	39.625h	50.125j
SD/BCW 1.0 mm 1:1	21.13fg	41.25h	59.95h	22.7kl	32.25n	44.75l
SD/BCW 1.0 mm 1:4	21.275f	37.675l	57.645j	25.725fg	40.725g	52.975i
SD/BCW 1.0 mm 1:8	19.98h	38.95k	54.65k	26.4e	43.15d	57.45f
SD/BCW 1.0 mm 1:16	26.575b	41.775gh	69.445e	24.025hi	34.275l	50.075j
SD/BCW 2.0 mm 1:1	26.58b	47.1d	69.3ef	25.3g	33.3m	44.3lm
SD/BCW 2.0 mm 1:4	14.435l	32.575n	49.575l	24.575hi	36.575j	40.375o
SD/BCW 2.0 mm 1:8	16.18k	32.55n	50.1l	26.1ef	42.35e	66.35c
SD/BCW 2.0 mm 1:16	23.37d	53.4b	72.1bc	26.7e	47.7b	57f
Control	11.05n	20.95q	21.05p	14.70o	17.35q	21.20q

Mean with the same superscript along the same column are not significantly different (p<0.05) treated withRH/BCW (1.0 mm) 1:1 compost. These plant heights were significantly (P < 0.05) higher than heights obtained in the remaining treated plots. Plant heights in some of the treated plots were not significantly different. The lowest plant height was measured in the control plot at 6 WAT.

4.9.3 Influence of compost treatments on *Amaranthus* height (cm) at 8 WAT in 2016 cropping season.

The *Amaranthuscruentus*plants fertilized with different compost treatments at 8weeks after transplanting (WAT) are presented on Plate 3. In 2016 season at 8 WAT, *Amaranthus* height was significantly(P<0.05)higher in plot treated withRH/BCW (0.5 mm) 1:16 compost(Plate 4) than in plottreated with RH/BCW (1.0 mm) 1:1 compost. Plant heights treated with RH/BCW (0.5 mm) 1:16 compost and RH/BCW (1.0 mm) 1:1 compost were not significantly different from the heights measured in plots treated withRH/BCW (0.5 mm) 1:1 compost and SD/BCW (2.0 mm) 1:16 compost. But these heights were significantly (P < 0.05) higher than the heights in the plots fertilized withother compost treatments. However, plant heights in some of the other compost treatments were not significantly different. Thelowest *Amaranthus* height was obtained in the control plot at 8 WAT.

4.9.4 *Amaranthus* height (cm) at 4 WAT in 2017 cropping season as influenced by different compost treatments.

In 2017 season at 4 weeks after transplanting (WAT), *Amaranthus* height was significantly(P<0.05)higher in plot treated withRH/BCW (1.0 mm) 1:16 compostthan in plottreated with RH/BCW (0.5 mm) 1:8 compost.Theseheightswere significantly higher than heights measured in plots treated withthe remaining compost treatments. The lowest plant height was obtained in the control at 4 WAT.

PLATE 2:*Amaranthus cruentus*at 4 WAT fertilized with different compost treatments

PLATE 3:*Amaranthus cruentus* plants at 8 WAT fertilized with differentcompost treatments

AT 8 WEEKS AFTER TRANSPLANTING (BLOCK

PLATE 4: *Amaranthus cruentus* with the highest height fertilized with RH/BCW compost prepared in 1:16 composting ratio with 0.5 mm particle size

4.9.5 Effects of compost types, particle sizes and composting ratios on *Amaranthus* height (cm) at 6 WAT in 2017 cropping season.

In 2017 season at 6weeks after transplanting (WAT), *Amaranthus* heights werenot significantly($P<0.05$)different in plots treated withRH/BCW (0.5 mm) 1:8 composting ratioandRH/BCW (1.0 mm) 1:16 compost.But these heights were higher than the heights measured in plots treated withother compost treatments. Some of the plant heights in the remaining treated plots were not statistically different. The lowest height was obtained in the control at 6 WAT.

4.9.6 Influence of different compost treatments on *Amaranthus* height (cm) at 8 WAT in 2017 cropping season.

In 2017 season at 8weeks after transplanting (WAT), *Amaranthus* height was significantly($P<0.05$)higher in plot treated withRH/BCW (0.5 mm) 1:8 compostthan in plottreated with RH/BCW (1.0 mm) 1:16 compost These plant heightswere significantly ($P < 0.05$) higher than the heights measured in plots treated withthe remaining compost treatments. The lowest plant height was obtained in the control at 8 WAT.

Plantheights of*Amaranthus cruentus*that received different compost treatments significantly ($P < 0.05$) differedat 4and 8 weeks after transplanting (WAT) in 2016 and 2017 planting seasons The highest *Amaranthus* height was observed in plots treated with RH/BCW (0.5 mm) 1:16 compostat 4, 6 and 8 weeks after transplanting(WAT) in 2016 cropping season whilethe highest *Amaranthus* height in 2017 cropping season was observed in plot treated with RH/BCW (1.0 mm)1:16compost at 4 weeks after transplanting(WAT)andin RH/BCW (0.5 mm) 1:8 compost at 6 and 8 weeks after transplanting (WAT).The highest *Amaranthus* height(74 cm) was obtained in plots that received RH/BCW (0.5 mm)1:16compostin

2016 season at 8 WATbut in 2017 planting season, the highest *Amaranthus* height(72 cm)was obtained in plots treated with RH/BCW (0.5 mm) 1:8 compost at 8 WAT (Table 9).

The plant height of *Amaranthus cruentus* differed significantly among the different compost treatments relative to the control in both cropping seasons. This observation might have been enhanced by the nutrient contents of composts usedas incorporating organic fertilizer into the soil for crop production has direct role in plant growth as a source of all necessary macro and micronutrients in available forms during mineralization. At 8 weeks after transplanting (WAT), *Amaranthus* plants grown on soils treated with RH/BCW (0.5 mm) 1:16 compost and RH/BCW (0.5 mm) 1:8 compost in 2016 and 2017 seasons, respectively were significantly ($P < 0.05$) taller than those grown on other treatments and the control. Emede *et al.* (2012) repoted that poultry manure applied to *Amaranthus cruentus* at the rates of 0, 5, 10, 15 and 20 t/ha,showed significant differences in plant height which reflects the effect of organic fertilizer on plant growth. Generally, RH/BCW and SD/BCW composts produced significantly ($P < 0.05$) taller plants relative to the control. The control plot recorded the lowest plant heights at 8 WAT with average height of 21.0 cm in 2016 and 2017 cropping seasonsas the plants depended on the inherent fertility of the soil that was reported to be low Chude *et al.* (2005).Plant height is positively correlated with the productivity of plants (Saeed *et al.*, 2007). The plant height increased significantly as the particle size of the composting materials decreases and the quantity of poultry manure in the composts increases. The highest height observed in the treated plants may be due toadditional nutrients from the compost treatments (Onwudike *et al.*, 2015)observed significant higher maize height treated with rice mill waste and poultry manure relative to control.

4.9.7 Effects of compost types and particle sizes on *Amaranthus* height (cm) at 4, 6 and 8 weeks after transplanting(WAT) in 2016 cropping season.

At four(4)weeks after transplanting (WAT), *Amaranthus* height was significantly(P<0.05)higher in plot treated with SD/BCW (1.0 mm)compost >SD/BCW (0.5 mm)compost>SD/BCW (2.0 mm)compost= RH/BCW (0.5 mm)compost= RH/BCW (1.0 mm)compost =RH/BCW (2.0 mm)compost in 2016 cropping season.

At six (6) WAT, *Amaranthus* height was significantly(P<0.05)higher in plot treated with SD/BCW (0.5 mm) compost >RH/BCW (0.5 mm) compost > SD/BCW (2.0 mm) compost > RH/BCW (2.0 mm) compost = SD/BCW (1.0 mm) compost > RH/BCW (1.0 mm) compost in 2016 season.

At eight(8) WAT, *Amaranthus* height was significantly(P<0.05)higher in plot treated with RH/BCW (0.5 mm) compost > SD/BCW (0.5 mm) compost > RH/BCW (2.0 mm) compost > SD/BCW (1.0 mm) compost = SD/BCW (2.0 mm) compost ≥ RH/BCW (1.0 mm) compost in 2016 season (Figure 12).

4.9.8 Effects of compost types and particle sizes on *Amaranthus* height (cm) at 4, 6 and 8 weeks after transplanting (WAT) in 2017 cropping season.

In 2017 cropping season, *Amaranthus* height was significantly (P<0.05)higher in plots treated with RH/BCW (1.0 mm) compost > RH/BCW (2.0 mm) compost > RH/BCW (0.5 mm) compost = SD/BCW (2.0 mm) compost > SD/BCW (1.0 mm) compost > SD/BCW (0.5 mm) compost at 4 WAT.

At 6 WAT,*Amaranthus* height was not significantly (P<0.05) higher in plot treated with RH/BCW (1.0 mm) compost = RH/BCW (0.5 mm) compost = SD/BCW (2.0 mm) compost ≥ RH/BCW (2.0 mm) compost = SD/BCW (1.0 mm) compost ≥ SD/BCW (0.5 mm) compost in 2017 season.

At 8 WAT,*Amaranthus* height was significantly ($P<0.05$) higher in plot treated with RH/BCW (0.5 mm) compost > RH/BCW (1.0 mm) compost > RH/BCW (2.0 mm) compost > SD/BCW (2.0 mm) compost = SD/BCW (1.0 mm) compost > SD/BCW (0.5 mm) compost in 2017 season (Figure 13).

4.10 Stem girth of *Amaranthuscruentus*(cm) at 2, 4, 6 and 8 WAT in 2016 and 2017 planting seasons as influenced by different compost treatments.

Data on the stem girth of *Amaranthuscruentus*as influenced by the various compost treatments in 2016 and 2017 cropping seasonsat 4, 6 and 8 weeks after transplanting (WAT) are presented in Table 10.The seedlings were transplanted at average stem girth of0.3 cm in both seasons at 2 weeks after sowing.

4.10.1 Effects of compost treatments on the stem girth of *Amaranthus cruentus* (cm) at 4 WAT in 2016 cropping season.

In 2016 season at 4 weeks after transplanting (WAT), *Amaranthus*stem girths werenot significantly($P<0.05$)different in plots treated withSD/BCW (1.0 mm) 1:16 compostand RH/BCW (1.0 mm) 1:16 compost. These values were not different from values obtained in plots amended with RH/BCW (0.5 mm) 1:16 compost and SD/BCW (2.0 mm) 1:16 compost. However, these stem girths were significantly higher than thestem girthsin plots treated withthe remaining compost treatments. Some of the stem girths were not statistically different. The lowest stem girth of *Amaranthus*was obtained in the control at 4 WAT.

.4.10.2 Effects of compost treatments on the stem girth of *Amaranthus cruentus* (cm) at 6 WAT in 2016 cropping season. In 2016 season at 6weeks after transplanting (WAT), the stem girth of *Amaranthus* was significantly($P<0.05$)higher in plants treated withSD/BCW (1.0 mm) 1:16 compostthan in plantstreated with SD/BCW (0.5 mm) 1:16 compost. These stem girths were not significantly ($P < 0.05$) different from the girths measured in plants treated withSD/BCW (2.0 mm) 1:16 compost, RH/BCW (0.5 mm) 1:16 compost and SD/BCW (1.0 mm) 1:4 compost.

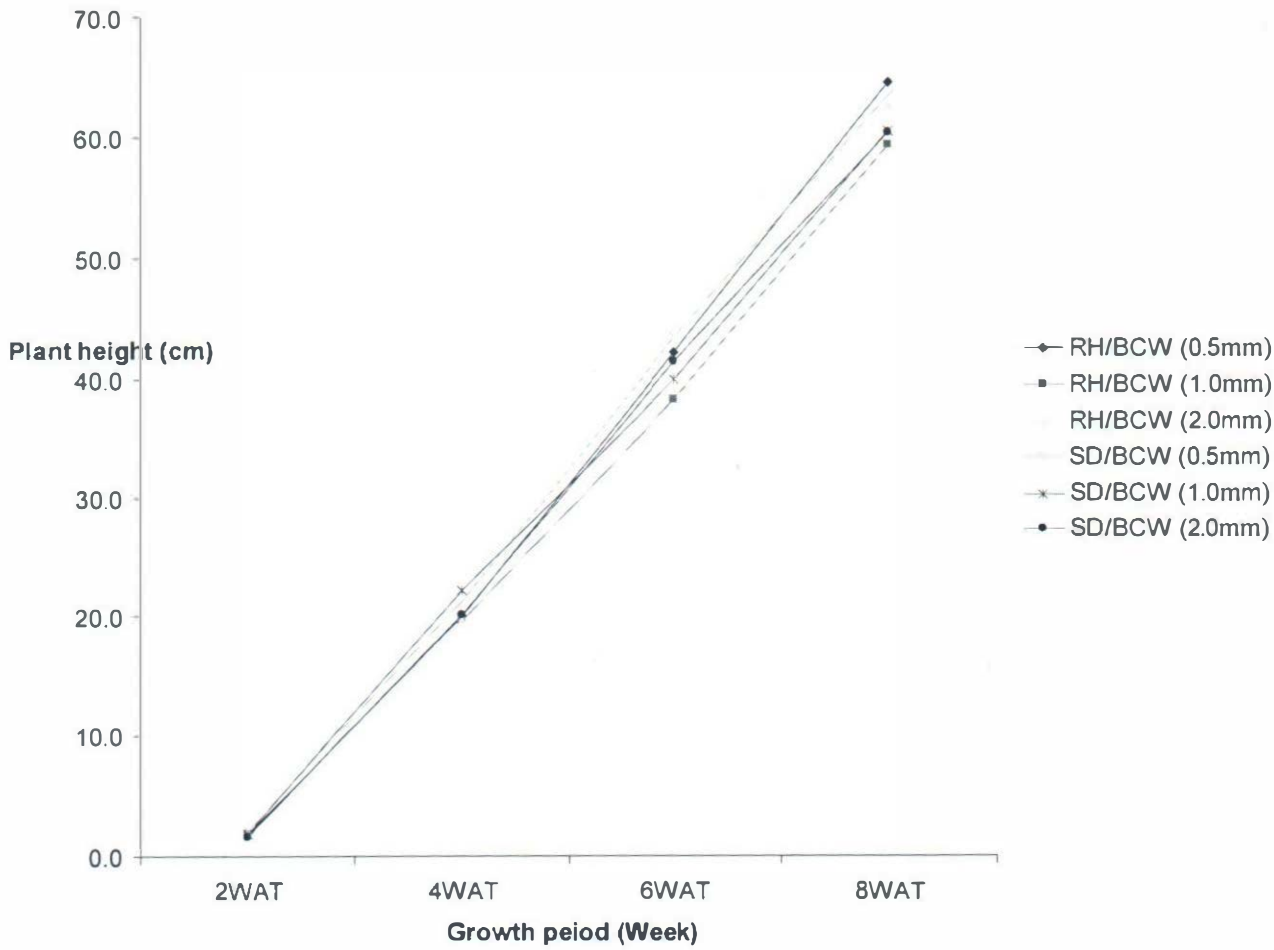


FIG 12:Effects of compost treatments on plant height of *Amaranthus cruentus*in 2016 season

LEGEND:

2 WAT 4 WAT 6WAT 8WAT
Not significant SD/BCW (1.0 mm) a SD/BCW (0.5 mm) a RH/BCW (0.5 mm) a
SD/BCW (0.5 mm) bRH/BCW (0.5 mm) bSD/BCW (0.5 mm) b
SD/BCW (2.0 mm) cSD/BCW (2.0 mm) cRH/BCW (2.0 mm) c
RH/BCW (0.5 mm) cRH/BCW (2.0 mm) dSD/BCW (1.0 mm) d
RH/BCW (1.0 mm) cSD/BCW (1.0 mm) dSD/BCW (2.0 mm) d
RH/BCW (2.0 mm) cRH/BCW (1.0 mm) eRH/BCW (1.0 mm) de

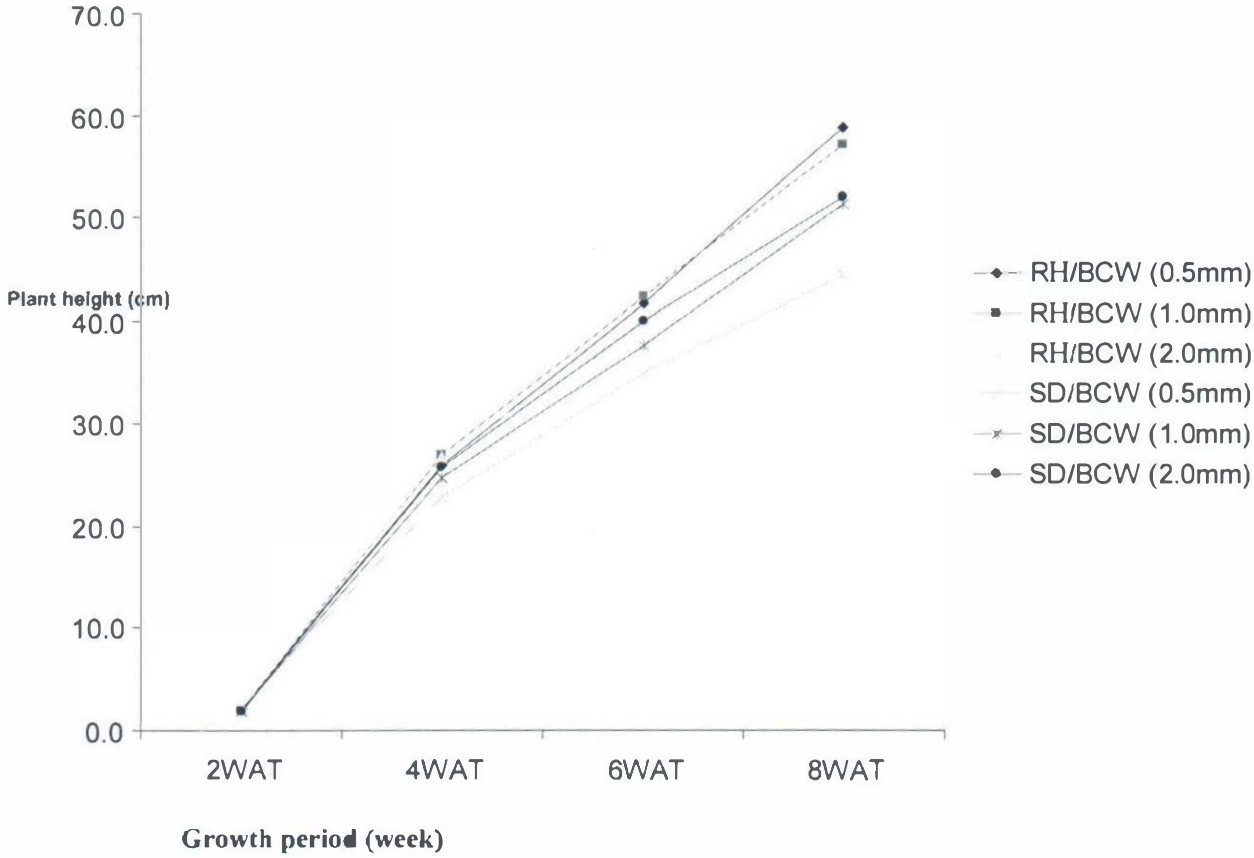


FIG.13:Effects of compost treatments on plant height of *Amaranthus cruentus*in 2017 season

LEGEND:

2 WAT	4 WAT	6WAT	8WAT
Not significant	RH/BCW (1.0 mm) a	RH/BCW (1.0 mm) a	RH/BCW (0.5 mm) a
	RH/BCW (2.0 mm) b	RH/BCW (0.5 mm) a	RH/BCW (1.0 mm) b
	RH/BCW (0.5 mm) c	SD/BCW (2.0 mm) a	RH/BCW (2.0 mm) c
	SD/BCW (2.0 mm) c	RH/BCW (2.0 mm) ab	SD/BCW (2.0 mm) d
	SD/BCW (1.0 mm) d	SD/BCW (1.0 mm) b	SD/BCW (1.0 mm) d
	SD/BCW (0.5 mm) e	SD/BCW (0.5 mm) bc	SD/BCW (0.5 mm) e

TABLE 10

Effect of compost treatments on stem girth of *Amaranthuscruentus*in 2016 and 2017 planting seasons

Stem girth (cm)						
	2016			2017		
Treatment	4WAT	6WAT	8WAT	4WAT	6WAT	8WAT
RH/BCW 0.5 mm 1:1	4.255cde	5.925de	7.305f	3.975fgh	4.555efg	4.775h
RH/BCW 0.5 mm 1:4	2.88k	4.6h	4.9k	4.53cdef	6.85ab	9.58a
RH/BCW 0.5 mm 1:8	3.48hij	6.12cde	7.35ef	5.15ab	6.05b	7.2bcde
RH/BCW 0.5 mm 1:16	4.885ab	7.005b	8.555cd	4.555bcdef	5.405cd	6.855cdef
RH/BCW 1.0 mm 1:1	4.11cdefg	6.11cde	7.27f	4.15efgh	4.8ef	6.43efgh
RH/BCW 1.0 mm 1:4	3.355ijk	4.695h	5.325k	4.545bcdef	5.675bcd	7.305bcde
RH/BCW 1.0 mm 1:8	3.92defghi	6.13cd	8.03cd	4.05efgh	5.55c	6.55efgh
RH/BCW 1.0 mm 1:16	4.975ab	5.805de	8.055cd	5.575a	7.105a	8.725ab
RH/BCW 2.0 mm 1:1	3.7efghi	5.89de	7.04fg	4.8bcd	5.75bc	7.45bcd
RH/BCW 2.0 mm 1:4	4.195cdef	5.515efg	6.275hi	4.925bc	5.925bc	6.805cdef
RH/BCW 2.0 mm 1:8	3.95defghi	5.87de	8.58c	4.65bcd	5.48c	6.43efg
RH/BCW 2.0 mm 1:16	4.05cdefgh	5.15fgh	6.64gh	3.9hg	5.1cd	6.03fgh
SD/BCW 0.5 mm 1:1	3.625efghij	5.155fgh	6.295hi	3.705h	3.755h	4.755h
SD/BCW 0.5 mm 1:4	3.77efghij	5.85de	6.53ghi	4.4 cdefg	4.9ef	5.85fgh
SD/BCW 0.5 mm 1:8	3.43ijk	4.79h	5.95ij	4.15efgh	4.88ef	5.67gh
SD/BCW 0.5 mm 1:16	4.525bcd	7.255b	9.345b	4.375cdefg	5.025cd	5.805fgh
SD/BCW 1.0 mm 1:1	4.46bcd	5.81de	7.09fg	3.95fgh	4.1fgh	4.63h
SD/BCW 1.0 mm 1:4	3.505ghij	6.675bc	8.545cd	4.555bcdef	5.675bcd	6.575efg
SD/BCW 1.0 mm 1:8	3.81efghi	5.95de	6.93fg	4.65bcde	6.13b	7.63bc
SD/BCW 1.0 mm 1:16	5.175a	8.055a	10.155a	3.905gh	5.025cd	5.675gh
SD/BCW 2.0 mm 1:1	4.43bcd	6.09cde	7.04fg	4.1efgh	4.68efg	4.8h
SD/BCW 2.0 mm 1:4	3.175jk	5.015gh	5.405jk	4.255defgh	4.905ef	5.455ghi
SD/BCW 2.0 mm 1:8	3.67efghij	5.65def	7.95de	4.5cdef	5.65bcd	6.88cdef
SD/BCW 2.0 mm 1:16	4.61abc	7.17b	8.58c	4.38cdefg	5.78bc	5.83fgh
Control	1.71l	2.92i	3.04l	1.53i	1.72i	2.32i

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

But these stem girths were significantly higher than the girths measured in plot treated with the remaining compost treatments. However, some of the stem girths were not significantly different. The lowest stem girth was measured in plot without treatment (control) at 6 WAT.

4.10.3 Stem girth of *Amaranthus cruentus* (cm) at 8 WAT in 2016 cropping season under different compost treatments.

In 2016 season at 8weeks after transplanting (WAT), the stem girth of*Amaranthus* was significantly($P<0.05$)higher in plot treated withSD/BCW (1.0 mm) 1:16 compostthan in plottreated with SD/BCW (0.5 mm) 1:16 compost.These values were significantly higher than the stem girths measured in plots treated withthe remaining compost treatments. However, some of the remaining stem girths were significantly different. The least stem girth was obtained in the control at 8 WAT.

4.10.4 Effects of compost treatments on the stem girth of *Amaranthus* (cm) at 4 WAT in 2017 cropping season.

In 2017 season at 4 weeks after transplanting (WAT), the stem girths of *Amaranthus* werenot significantly($P<0.05$)different in plots treated withRH/BCW (1.0 mm) 1:16 compostand RH/BCW (0.5 mm) 1:8 compost. But these were higher thanthe stem girthsin plotsfertilized withthe rest of the compost treatments. Although some of the stem girths were not statistically different from others. The lowest stem girth was obtained in the control plot at 4 WAT.

4.10.5 Influence of different compost treatments on stem girth of *Amaranthus*(cm) at 6 WAT in 2017 cropping season.

In 2017 season at 6weeks after transplanting (WAT), the stem girth of *Amaranthus*treated withRH/BCW (1.0 mm) 1:16 compost wasnot significantly(P<0.05) different from the girth treated with RH/BCW (0.5 mm) 1:4 compost.These stem girths were higher than the stem girths of plants amended with the remaining compost treatments. However, some of the stem girths were not significantly different. The least stem girth was obtained in the control plot at 6 WAT.

4.10.6Stem girth of *Amaranthus* (cm) at 8 WAT in 2017 cropping season as influenced by different compost treatments.

In 2017 season at 8weeks after transplanting (WAT), the stem girth of *Amaranthus*in plot treated withRH/BCW (0.5 mm) 1:4 compostwas not significantly(P<0.05)different from its value in plant treated with RH/BCW (1.0 mm) 1:16 compost.*Amaranthuscruentus* fertilized with RH/BCW (0.5 mm) 1:4 compost recorded the widest stem girth (Plate 5). The stem girthsamended with these compost treatments were higher than the stem girths of plants treated withRH/BCW (0.5 mm) 1:8 compost and RH/BCW (1.0 mm) 1:4 compost. These stem girths were not statistically different from the girths in plants treated with RH/BCW (2.0 mm) 1:1 compost and SD/BCW (1.0 mm) 1:8 compost.But these stem girths were significantly higher than the girths obtained in plants amended with the rest of the compost treatments. Nevertheless, some of the remaining stem girths were not significantly different. The lowest stem girth was obtained in the control plot.

The stem girthsof *Amaranthuscruentus*significantly (P < 0.05) differed at 4 and 8 weeks after transplanting (WAT) in 2016 and 2017 seasons. The widest*Amaranthus* stem girth in 2016 season was observed in plots treated with SD/BCW (1.0 mm) 1:16 compostat 4, 6 and 8 weeks after transplanting(WAT)and inRH/BCW (1.0 mm)1:16compost at 4and 6WAT and in RH/BCW (0.5 mm) 1:4 compost at 8 weeks after transplanting(WAT)in 2017 planting season.

PLATE 5:*Amaranthus cruentus* with the widest stem girth fertilized with RH/BCW compost prepared in 1:4 composting ratio with 0.5 mm particle size

The stem girths of *Amaranthus* in the control plotsfor the two cropping seasons were significantly ($P < 0.05$) lower than the stem girths of plants under different compost treatments.The widest stem girth (10.16 cm) at 8 WAT in 2016 cropping season was obtained in SD/BCW (1:16) 1.0 mm compost treatment and 9.53 cmin RH/BCW (1:4) 0.5 mm compost at 8 WAT in 2017 cropping season. The stem girth increased with increase in the number of weeks after transplanting of the seedlings (Table 10). Swine waste with initial C/N ratio of 16:1 composted with sawdust with initial C/N ratio of 64:1 was reported (Ekong *et al.*, 2017) to significantly ($P<0.05$) increased the growth parameters of eggplant in acid soils of Obio Akpa, Akwa Ibom State.

4.10.7 Effects of compost types and particle sizes on the stem girth of *Amaranthus* (cm) at 4, 6 and 8 weeks after transplanting (WAT) in 2016 cropping season.

At four(4)weeks after transplanting (WAT), the stem girth of *Amaranthus* was significantly($P<0.05$)higher in plants treated with SD/BCW (1.0 mm)compost> RH/BCW (1.0 mm)compost > RH/BCW (2.0 mm)compost =SD/BCW (2.0 mm)compost >RH/BCW (0.5 mm)compost = SD/BCW (0.5 mm)compost in 2016 cropping season.

At six (6) WAT in 2016 season, the stem girth of *Amaranthus*was significantly($P<0.05$)higher in plants treated with SD/BCW (1.0 mm)compost>SD/BCW (2.0mm) compost > RH/BCW (0.5 mm) compost > SD/BCW (0.5 mm) compost = RH/BCW (1.0 mm) compost = RH/BCW (2.0 mm) compost in 2016 planting season.

At eight (8) WAT, the stem girth of *Amaranthus* was significantly($P<0.05$)higher in plants treated with SD/BCW (1.0 mm) compost > SD/BCW (2.0 mm) compost = RH/BCW (1.0 mm) compost =RH/BCW (2.0 mm) compost ≥RH/BCW (0.5 mm) compost =SD/BCW (0.5 mm)compost in 2016 planting season (Figure 14).

4.10.8 Effects of compost types and particle sizes on the stem girth of *Amaranthus* (cm) at 4, 6 and 8 weeks after transplanting (WAT) in 2017 cropping season.

In 2017 cropping season at 4 WAT, the stem girth of *Amaranthus* was significantly (P<0.05)higher in plants treated with RH/BCW (1.0 mm) compost = RH/BCW (2.0 mm) compost = RH/BCW (0.5 mm) compost > SD/BCW (2.0 mm) compost = SD/BCW (1.0 mm) compost > SD/BCW (0.5 mm) compost.

At 6 WAT,the stem girth of *Amaranthus* was significantly (P<0.05) higher in plants treated with RH/BCW (1.0 mm) compost = RH/BCW (0.5 mm) compost = RH/BCW (2.0 mm) compost ≥ SD/BCW (2.0 mm) compost = SD/BCW (1.0 mm) compost ≥ SD/BCW (0.5 mm) compost in 2017 planting season.

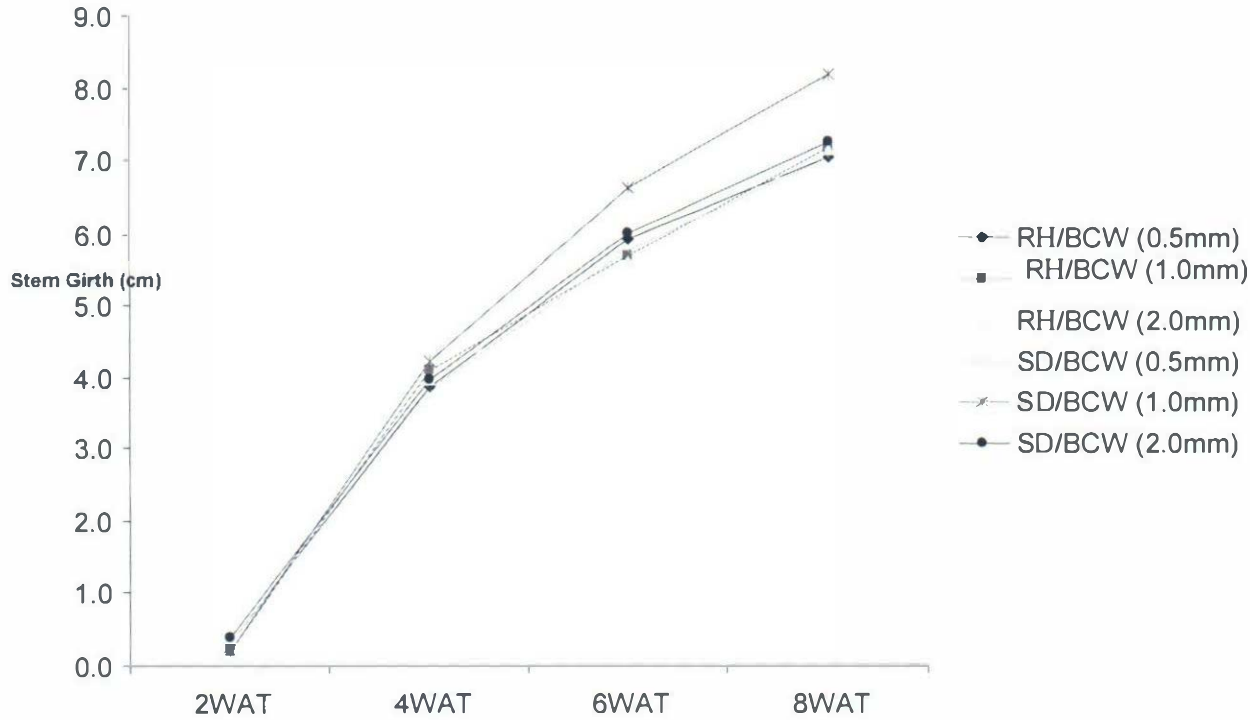
At 8 WAT, the stem girthof *Amaranthus cruentus*was significantly (P<0.05) higher in plants treated with RH/BCW (0.5 mm) compost = RH/BCW (1.0 mm) compost = RH/BCW (2.0 mm) compost ≥ SD/BCW (1.0 mm) compost ≥ SD/BCW (2.0 mm) compost = SD/BCW (0.5 mm)compost in 2017 season (Figure 15).

4.11Effects of compost treatments on the leaf area of *Amaranthuscruentus*(cm^2) at4, 6 and 8 WAT in 2016 and 2017 cropping seasons.

Data generated on the leaf area of *Amaranthus*in 2016 and 2017 seasons under different compost treatments at4, 6 and 8 weeks after transplanting (WAT) are presented in Table11.The seedlings were transplanted at average leaf area of 1.4 cm^2 in both seasons at 2 weeks after sowing.

4.11.1 Leaf area of *Amaranthus cruentus* (cm^2) at 4 WAT in 2016 cropping season under different compost treatments.

In 2016 season at 4 weeks after transplanting (WAT), the leaf area of *Amaranthus*treated withRH/BCW (0.5 mm) 1:8 compostwas significantly(P<0.05)higherthan the leaf area in plants treated with RH/BCW (1.0 mm)1:16 compost and SD/BCW (2.0 mm) 1:8 compost.



Growth period (week)

FIG. 14: Effects of compost treatments on stem girth of *Amaranthus cruentus*in 2016 season

LEGEND:

2 WAT	4 WAT	6WAT	8WAT
Not significant	SD/BCW (1.0 mm) a	SD/BCW (1.0 mm) a	SD/BCW (1.0 mm) a
	RH/BCW (1.0 mm) b	SD/BCW (2.0 mm) b	SD/BCW (2.0 mm) b
	RH/BCW (2.0 mm) c	RH/BCW (0.5 mm) c	RH/BCW (1.0 mm) b
	SD/BCW (2.0 mm) c	SD/BCW (0.5 mm) d	RH/BCW (2.0 mm) bc
	RH/BCW (0.5 mm) d	RH/BCW (1.0 mm) d	RH/BCW (0.5 mm) c
	SD/BCW (0.5 mm) d	RH/BCW (2.0 mm) d	SD/BCW (0.5 mm) c

The leaf areasin plantsamended with these treatments werehigher than the leaf areas of plants treated with the remaining compost treatments. The least value of leaf area was obtained in the control plot at 4 WAT.

4.11.2 Leaf area of *Amaranthuscruentus* (cm^2) at 6 WAT in 2016 cropping season a affected bydifferent compost treatments.

In 2016 season at 6weeks after transplanting (WAT), the leaf area of *Amaranthus* in plant treated withSD/BCW (2.0 mm) 1:16 compost was not significantly($P<0.05$) different the leaf area in plant treated with SD/BCW (1.0 mm) 1:16 compost. These values were higher than the leaf areas of plants treated withother compost treatments. However, the leaf areas of some of the remaining compost treatments did not differ from others. The lowest value of leaf area was obtained in the control plot at 6 WAT.

TABLE 11

Effect of compost treatments on *Amaranthuscruentus* leaf area in 2016 and 2017 planting seasons

	Leaf area (cm^2)					
	2016			2017		
Treatment	**4WAT**	**6WAT**	**8WAT**	**4WAT**	**6WAT**	**8WAT**
RH/BCW 0.5 mm 1:1	80.575mn	41.005bcdefg	42.675cdefg	44.055defg	40.725c	41.305defgh
RH/BCW 0.5 mm 1:4	97.45c	38.13k	39.85j	40.15j	39.78e	42.1bcde
RH/BCW 0.5 mm 1:8	108.15a	39.23ijk	41.87fgh	43.1fgh	40.9c	41.8cde
RH/BCW 0.5 mm 1:16	91.175hi	39.135ijk	41.255hij	42.805fgh	38.805f	39.655i
RH/BCW 1.0 mm 1:1	77.75op	40.61cdefghi	42.61defgh	43.77efg	40.65cd	41.3defgh
RH/BCW 1.0 mm 1:4	90.975hi	38.855jk	40.195ij	40.825ij	40.045e	41.175def
RH/BCW 1.0 mm 1:8	97.15cd	39.42hjk	41.63ghi	43.53efgh	39.55efgh	41.05def
RH/BCW 1.0 mm 1:16	104.275b	39.475ghijk	40.305ij	42.555gh	40.075e	41.605cde
RH/BCW 2.0 mm 1:1	91.85gh	41.45bcde	43.64cde	44.79cde	42.55b	43.5abc
RH/BCW 2.0 mm 1:4	93.375fg	40.195defghi	41.515gih	42.275hi	40.925c	41.925cd
RH/BCW 2.0 mm 1:8	94.9ef	39.7ghij	41.62gih	44.33def	40.4def	41.23defgh
RH/BCW 2.0 mm 1:16	89.7ij	40.05efghij	41.15hij	42.64gh	39.9e	41.1defg
SD/BCW 0.5 mm 1:1	79.075nop	40.875bcdef	42.405efgh	43.545efgh	40.955c	41.005defg
SD/BCW 0.5 mm 1:4	83.15m	40.52cdefghi	42.6defgh	43.28efgh	41.1bc	41.65cdeg
SD/BCW 0.5 mm 1:8	76.95q	40.68cdef	42.04fgh	43.2fgh	41.4bc	42.13bcde
SD/BCW 0.5 mm 1:16	86.875lm	41.275bcde	44.005bcd	46.095bc	41.125bc	41.775cdef
SD/BCW 1.0 mm 1:1	82m	41.71bcd	43.06cdefg	44.34def	41.2bc	41.35dcef
SD/BCW 1.0 mm 1:4	89.225j	39.755ghij	42.925cdefg	44.795cde	40.805c	41.925cd
SD/BCW 1.0 mm 1:8	95.7de	42.06bc	44.2bc	45.18cd	42.9ab	44.38ab
SD/BCW 1.0 mm 1:16	87.325k	42.425ab	45.305ab	47.405ab	41.155bcd	42.275bcd
SD/BCW 2.0 mm 1:1	79.55no	39.68ghij	41.34hij	42.29hi	39.35ef	39.93hi
SD/BCW 2.0 mm 1:4	78.625op	41.425bcde	43.265cdef	43.7 defgh	42.505b	43.155abc
SD/BCW 2.0 mm 1:8	103.6b	40.92bcdefg	42.9cdefg	45.2cd	41.75bc	42.9bcd
SD/BCW 2.0 mm 1:16	96.25cde	43.86a	46.42a	47.83a	43.63a	45.03a
Control	23.21r	36.01	27.60k	6.24k	7.86g	11.80j

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

4.11.3 Influence of different compost treatments on the leaf area of *Amaranthus*(cm^2) at 8 WAT in 2016 cropping season.

In 2016 season at 8weeks after transplanting (WAT), the leaf area of *Amaranthus*in plant treated withSD/BCW (2.0 mm) 1:16 compostwas not significantly($P<0.05$)different from the leaf area of plant in plottreated with SD/BCW (1.0 mm) 1:16 compost.The broadest leaf area was obtained in plants treated with SD/BCW (2.0 mm) 1:16 compost (Plate 6). These valuesof leaf area were significantly higher than the values in plants treated withother compost treatments. But some values in the remaining compost treatments did not differ from others.The lowest leaf area was obtained in the control at 8 WAT.

4.11.4 Leaf area of *Amaranthus* (cm^2) at 4 WAT in 2017 cropping season under different compost treatments.

In 2017 season at 4 weeks after transplanting (WAT), the leaf area of *Amaranthus* was not significantly($P<0.05$) different in plots treated withSD/BCW (2.0 mm) 1:16 compostand SD/BCW (1.0 mm) 1:16 compost. But these were significantly higher than leaf areas of plant treated withthe remaining compost treatments. Although some values of leaf area in the remaining compost treatments were not significantly different from others. The lowest leaf area was obtained in plants in the control at 4 WAT.

4.11.5 Influence of different compost treatments on the leaf area of *Amaranthus* (cm^2) at 6 WAT in 2017 cropping season.

In 2017 season at 6weeks after transplanting (WAT), the leaf area of *Amaranthus* in plots treated withSD/BCW (2.0 mm) 1:16 compostdidnot significantly($P<0.05$) differ from the leaf area of plant treated with SD/BCW (1.0 mm) 1:8 compost.

PLATE 6: *Amaranthus cruentus* with the broadest leaf area fertilized with SD/BCW compost prepared in 1:16composting ratio with 2.0 mm particle size

But theseleaf areas werehigher than leaf areasin plot treated withthe remaining compost treatments. However, some of the leaf areas in the remaining compost treatments did not differ from others. The least leaf area was obtained in the control plot at 6 WAT.

4.11.6 Leaf area of *Amaranthus* (cm^2) at 8 WAT in 2017 cropping season as influenced by different compost treatments.

In 2017 season at 8weeks after transplanting (WAT), the leaf areas of *Amaranthus* werenot significantly(P<0.05) different in plots treated withSD/BCW (2.0 mm) 1:16 compostand SD/BCW (1.0 mm) 1:8 compost.These were not also different from leaf areas of plants treated with RH/BCW (2.0 mm) 1:1 compostand SD/BCW (2.0 mm) 1:4 compost.However, these leaf areas were higher than the leaf areas in plants treated with the remaining compost treatments. Some of the leaf areas in the remaining treated plots did not differ. The lowest leaf area was obtained in the control plot at 8 WAT.

4.11.7 Effects of compost types and particle sizes on the leaf area of *Amaranthus* (cm^2) at 4, 6 and 8 weeks after transplanting (WAT) in 2016 cropping season.

At four(4)weeks after transplanting (WAT), the leafarea of *Amaranthus* was significantly(P<0.05)higher in plots treated with SD/BCW (1.0 mm)compost =SD/BCW (2.0 mm)compost >SD/BCW (0.5 mm)compost > RH/BCW (2.0 mm)compost >RH/BCW (1.0 mm)compost > RH/BCW (0.5 mm)compost in 2016 cropping season.

At six (6) WAT in 2016 season, the leafarea of *Amaranthus*was significantly(P<0.05)higher in plots treated with SD/BCW (2.0 mm)compost = SD/BCW (1.0mm) compost > SD/BCW (0.5 mm) compost > RH/BCW (2.0 mm) compost > RH/BCW (1.0 mm) compost > RH/BCW (0.5 mm) compost.

At eight (8) WAT, the leafarea of *Amaranthus* was significantly(P<0.05)higher in plots treated with SD/BCW (1.0 mm) compost > SD/BCW (2.0 mm) compost >SD/BCW (0.5 mm) compost >RH/BCW (2.0 mm) compost >RH/BCW (0.5 mm) compost =RH/BCW (1.0 mm)compost in 2016 season (Figure 16).

4.11.8 Effects of compost types and particle sizes on the leafarea of *Amaranthus* (cm^2) at 4, 6 and 8 weeks after transplanting (WAT) in 2017 cropping season.

In 2017 cropping season at 4 WAT, the leaf of *Amaranthus* was significantly (P<0.05)higher in plots treated withSD/BCW (1.0 mm) compost =SD/BCW (2.0 mm) compost >SD/BCW (0.5 mm) compost >RH/BCW (2.0 mm) compost >RH/BCW (1.0 mm) compost =RH/BCW (0.5 mm) compost.

At 6 WAT,the leaf of *Amaranthus* was not significantly (P<0.05) different inany of the treated plots.

At 8 WAT in 2017 season, the leaf area was significantly (P<0.05) higher in plots treated withSD/BCW (2.0 mm) compost >SD/BCW (1.0 mm) compost > RH/BCW (2.0 mm) compost > SD/BCW (0.5 mm) compost >RH/BCW (1.0 mm) compost =RH/BCW (0.5 mm)compost (Figure 17).

The leaf areaof *Amaranthuscruentus* was significantly (P < 0.05) different at 4 and 8 weeks after transplanting (WAT) in 2016 and 2017 seasons. The broadestleaf area of *Amaranthus* in 2016 season was observed in plants treated with RH/BCW (0.5 mm) 1:8 compostat 4 weeks after transplanting(WAT) and in SD/BCW (2.0 mm) 1:16 compost at 6 and 8 WAT. In 2017 planting season, SD/BCW (2.0 mm)1:16compost recorded the highest leaf area at 4, 6 and 8 weeks after transplanting(WAT).

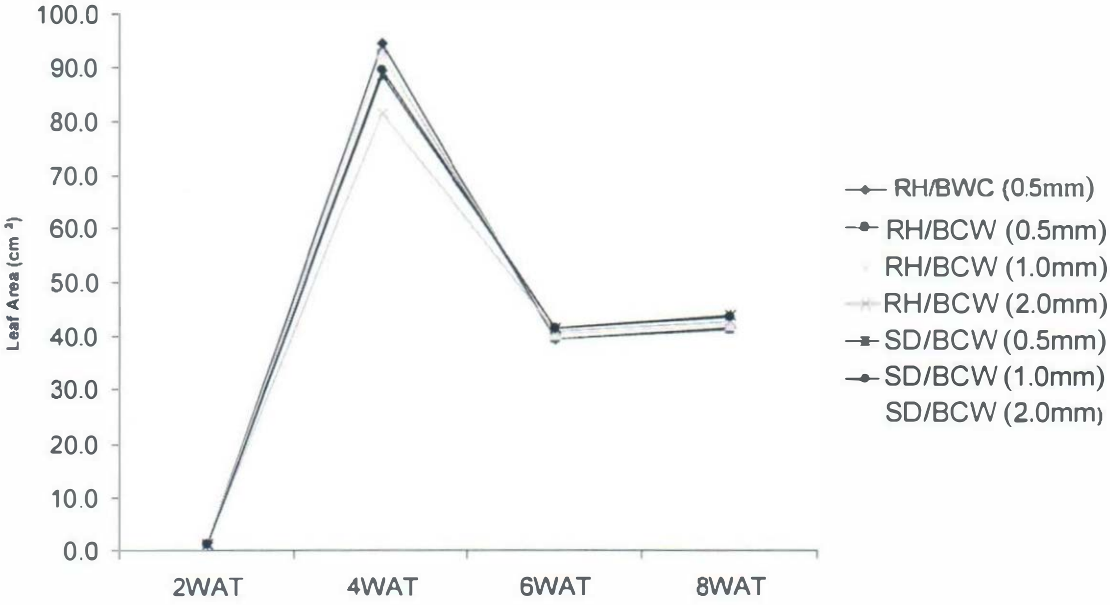
At 8 weeks after transplanting (WAT),*Amaranthuscruentus* fertilized with SD/BCW (2.0 mm) 1:16 compost had significantly (P < 0.05) larger leaf area (46.42 cm^2) in 2016 and (45.03 cm^2) in 2017 cropping seasons than other treatments and the control. The leaf area of *Amaranthus* grown on SD/BCW composts was significantly (P < 0.05) higher than the ones produced on RH/BCW composts and the control in both seasons. The poultry manure also had significant increase in the leaf area of the test crop. The increase in leaf area had been claimed to be directly influenced by nitrogen supply in fertilizer applied (Ehigiator, 1990). The leaf area of plants on the treated plot was significantly higher than those in the untreated plots in the two seasons. The effect of poultry manure on the increase of leaf area index of amaranth was reported by Eghareyba and Ogbe (2002). The leaf area gives information about the photosynthetic potential as well as the growth rate of plants.

4.12 Plant nutrient contentsin*Amaranthuscruentus*as influenced by compost types, particle sizes and composting ratios of the prepared compostsat 9 weeks after transplanting (WAT) in 2016 and 2017 cropping seasons.

The nutrient contents in*Amaranthuscruentus*as influenced by the application of different compost treatments in 2016 and 2017 cropping seasonsat 9 weeks after transplanting (WAT) are presented in Tables12 and 13.

4.12.1 Nitrogen content in *Amaranthuscruentus* at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The nitrogen contents in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season were not significantly (P < 0.05) different in plants that received SD/BCW (2.0 mm) 1:4 compost and SD/BCW (2.0 mm) 1:8 compost. These nitrogen contents were not different from the contents in plants amended with some compost treatments.

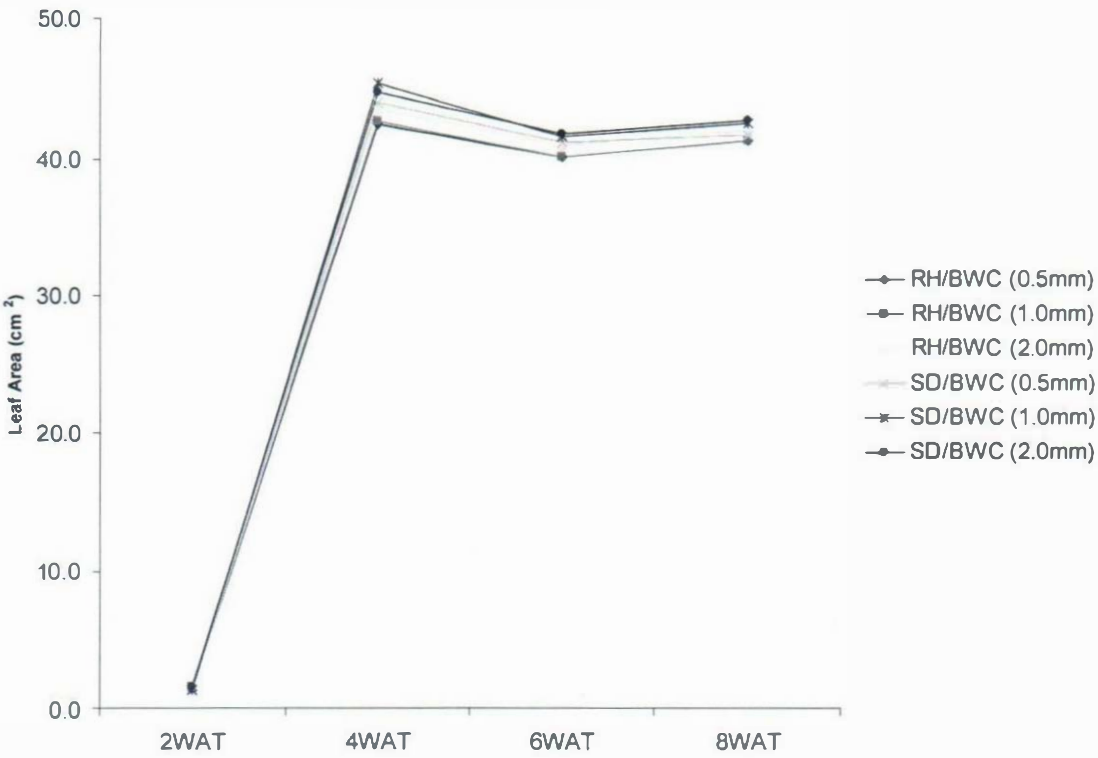


Growth period (week)

FIG. 16: Effects of compost treatments on leaf area of *Amaranthus cruentus*in 2016 season

LEGEND:

2 WAT	4 WAT	6WAT	8WAT
Not significant	SD/BCW (1.0 mm) a	SD/BCW (2.0 mm) a	SD/BCW (1.0 mm) a
	SD/BCW (2.0 mm) a	SD/BCW (1.0 mm) a	SD/BCW (2.0 mm) b
	SD/BCW (0.5 mm) b	SD/BCW (0.5 mm) b	SD/BCW (0.5 mm) c
	RH/BCW (2.0 mm) c	RH/BCW (2.0 mm) c	RH/BCW (2.0 mm) d
	RH/BCW (1.0 mm) d	RH/BCW (1.0 mm) d	RH/BCW (0.5 mm)
	eRH/BCW (0.5 mm) e	RH/BCW (0.5 mm) e	RH/BCW (1.0 mm) e



Growth period (week)

FIG.17: Effects of compost treatments on leaf area of *Amaranthus cruentus* in 2017 season

LEGEND:

2 WAT 4 WAT 6WAT 8WAT
Not significant SD/BCW (1.0 mm) a Not significant SD/BCW (2.0 mm) a
SD/BCW (2.0 mm) a SD/BCW (1.0 mm) b
SD/BCW (0.5 mm) bRH/BCW (2.0 mm) b
RH/BCW (2.0 mm) cSD/BCW (0.5 mm) c
RH/BCW (1.0 mm) dRH/BCW (1.0 mm) d
RH/BCW (0.5 mm) d RH/BCW (0.5 mm) d

However, some of these contents were significantly (P < 0.05) higher than the contents in plants that received other compost treatments in which some contents were not statistically different from nitrogen content in the control. However, the nitrogen content in the control was significantly (P < 0.05) higher than the content in plants treated with SD/BCW (0.5 mm) 1:8 compost which was higher than the content in plants that received RH/BCW (2.0 mm) 1:1 compost and this was also higher than the nitrogen content in plants that received RH/BCW (0.5 mm) 1:8 compost.

The nitrogen content of *Amaranthuscruentus* in plants that received SD/BCW (2.0 mm) 1:4 compost at 9 weeks after transplanting (WAT) in 2017 cropping season was not statistically (P < 0.05) different from the content in plants treated with SD/BCW (2.0 mm) 1:8 compost. These contents were not different from the contents in plants amended with some of the compost treatments and the control.

Nitrogen contents of *Amaranthus cruentus* in these plants were significantly (P < 0.05) higher than the contents in plants that received the remaining compost treatments.However, some the nitrogen contents in the remaining plants were not statistically different. Nitrogen content in plants obtained in the control was higher than the contents in plants amended with some compost treatments.

4.12.2 Phosphorus content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The phosphorus content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly (P < 0.05) higher in plants that received SD/BCW (2.0 mm) 1:8 compostthan in plants that received RH/BCW (1.0 mm)1:8 compost.Thesecontentswere significantly (P < 0.05) higher than the contents in plants that received the remaining compost treatments. The phosphorus content in

TABLE 12

Nutrient contents in*Amaranthus* plant at 9 WAT as influenced by different compost treatments in 2016 cropping season

	N	P	K	Ca	Mg	Cu	Zn	Mn	Fe
Treatment	←				mgkg-1				→
RH/BCW 0.5 mm 1:1	4.525abcde	1742.5c	528.5j	49603.7e	11640e	2.125def	2.625p	42.925g	154.95r
RH/BCW 0.5 mm 1:4	4.76ab	1057.5i	537.5j	64003.86a	13820b	1.65fgh	22f	52.2c	465.95f
RH/BCW 0.5 mm 1:8	2.14i	897.5l	2351.5gf	31601.74l	7195l	2.925bc	7.775m	11.55o	401.75h
RH/BCW 0.5 mm 1:16	4.425abcdef	690p	2365f	28003.3o	6262.3o	1.7fgh	15.25i	16.725m	424.83g
RH/BCW 1.0 mm 1:1	4.35bcd	185x	4705c	28003.4o	5750q	1.35hi	13.35j	43.15g	275.8n
RH/BCW 1.0 mm 1:4	4.115cdef	565s	2333h	16803.14w	3897.5v	5.475a	16.575h	26.325j	256.25o
RH/BCW 1.0 mm 1:8	3.95efgh	1767.5b	535.5j	40003.3i	9750g	1.85defgh	3.35o	49.85d	390.75h
RH/BCW 1.0 mm 1:16	4.355bcd	360v	2362.5gf	24003.58r	5137.5t	0.95j	9.875l	6.775q	335.55l
RH/BCW 2.0 mm 1:1	3.39h	1082.5h	500.5k	32002.59k	7450k	2.45cd	41a	32i	598.4b
RH/BCW 2.0 mm 1:4	4.045defg	735o	2385e	11602.97x	3037.5y	3.45b	28.65b	16.47m	311.45m
RH/BCW 2.0 mm 1:8	4.66abc	750n	4700cd	40003.81g	8725h	2.35cde	8.375m	15.15n	699.25a
RH/BCW 2.0 mm 1:16	4.34bcdef	955k	2350.5g	29203.64m	6765n	0.8j	21.55f	21.05l	361.1k
SD/BCW 0.5 mm 1:1	3.905fgh	635r	2349.5g	17603.08u	3252.5x	3.325b	27.475c	24.325k	130.85r
SD/BCW 0.5 mm 1:4	4.48abcdef	482.5t	2242.5i	40003.58h	8449.5i	1.8efgh	10.7k	43.2g	526.15d
SD/BCW 0.5 mm 1:8	3.65gh	1372.5f	537j	58403.25c	13050c	1.4ghi	25.35e	47f	383.7i
SD/BCW 0.5 mm 1:16	4.545abcde	665q	2355.3gf	23603.42s	5357.3s	1.65fgh	19.6g	11.675o	430.85g
SD/BCW 1.0 mm 1:1	4.81ab	1335g	4690d	28003.86n	6900m	2.05def	1.1q	52.05c	287.85n
SD/BCW 1.0 mm 1:4	4.625abcd	290w	2357.5gf	19203.65t	4062.5u	3.15b	15.025i	7.575p	376.65j
SD/BCW 1.0 mm 1:8	4.23bcdef	392.5u	2355gf	17203.58v	3814.8w	1.3hi	26.525d	26.1j	348.6l
SD/BCW 1.0 mm 1:16	3.965efgh	1672.5d	4857.5a	64003.19b	14450a	1.375hi	6.375n	57.875b	540.2c
SD/BCW 2.0 mm 1:1	4.44abcdef	1032.5j	2362.5gf	25578.64q	6120p	0.875j	19g	11.45o	381.65i
SD/BCW 2.0 mm 1:4	4.995a	1572.5e	532.5j	41603.92f	9870f	2.175def	1.275q	61.775a	202.5q
SD/BCW 2.0 mm 1:8	4.99a	1875a	540j	34404.14j	7734.5j	1.65fgh	15.3i	47.25f	229.7p
SD/BCW 2.0 mm 1:16	4.06cdef	780m	4730b	57603.36d	12270d	2defg	9.65l	48.8e	428.2g
Control	3.88fgh	1334.0g	4701.0cd	27250.0p	5458.0r	1.23i	21.90f	36.90h	470.47e

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

TABLE 13

Nutrient contents in *Amaranthus* plant at 9 WAT as influenced by different compost treatments in 2017 cropping season

Treatments	N	P	K	Ca	Mg	Cu	Zn	Mn	Fe
	←			mgkg-1					→
RH/BCW 0.5 mm 1:1	3.10abcde	1682.3c	402.3m	44202.25e	8882.3e	1.03ghi	1.43o	41.45h	134.70q
RH/BCW 0.5 mm 1:4	3.36ab	1008.3j	405.3lm	58803.25b	9908.3b	0.57kl	18.3f	52.35c	436.70e
RH/BCW 0.5 mm 1:8	1.48f	852.3m	2222.3hi	26172.25l	5202.3k	1.95c	5.61m	12.00rs	381.50g
RH/BCW 0.5 mm 1:16	2.75bcdef	645.8p	2240.8g	22802.75n	4502.8o	0.48l	11.61hi	16.55o	400.08f
RH/BCW 1.0 mm 1:1	2.92bc	135.5x	4523.5d	22823.50n	4803.5m	0.95hi	8.80j	43.90g	244.30n
RH/BCW 1.0 mm 1:4	2.59cdef	520.8s	2202.8j	11602.75w	2662.8t	3.68a	11.88hi	25.05l	231.50no
RH/BCW 1.0 mm 1:8	2.65cdef	1729.8b	419.8lm	34921.75g	7101.8g	1.26ef	1.58o	47.75e	375.0hg
RH/BCW 1.0 mm 1:16	2.98bc	320.3v	2242.3g	18862.25r	3602.3s	0.28mn	7.43k	8.10t	315.30k
RH/BCW 2.0 mm 1:1	2.09e	1033.3i	353.3n	26963.25k	5703.3j	1.38def	34.53a	31.55j	569.15b
RH/BCW 2.0 mm 1:4	2.37defg	702.3o	2262.3f	6802.25x	1752.3x	2.11b	22.73b	15.45o	291.20l
RH/BCW 2.0 mm 1:8	3.23abc	707.5o	4572.5c	34902.5h	7052.5h	1.55d	5.78lm	14.70p	676.75a
RH/BCW 2.0 mm 1:16	3.11ab	908l	2213hij	24003m	4723n	0.33m	19.15ef	22.30n	334.10j
SD/BCW 0.5 mm 1:1	2.48def	593.3r	2224.3hi	12402.25u	2402.3v	1.43d	20.43d	23.25m	110.60r
SD/BCW 0.5 mm 1:4	3.08abc	433.3t	2103.3k	34893.3i	6803.3i	0.83ij	7.33k	43.55g	496.90d
SD/BCW 0.5 mm 1:8	2.65cdef	1330.3f	422.3l	53202.3c	9502.3c	1.23efg	20.48d	43.05g	363.45hi
SD/BCW 0.5 mm 1:16	2.87bcde	620.8q	2227.8gh	18502.8s	3702.8r	0.48l	13.76g	12.15r	406.10f
SD/BCW 1.0 mm 1:1	3.38ab	1281.5gh	4558.5cd	22803.5n	4983.5l	1.15fg	1.40o	51.50d	256.35m
SD/BCW 1.0 mm 1:4	3.10abcde	244.8w	2332.8e	14102.8t	2652.8u	1.53d	11.28i	8.55s	351.90i
SD/BCW 1.0 mm 1:8	2.93bcd	351.8u	2231.8h	12001.8v	2231.8w	0.53kl	22.06c	25.10k	332.85jk
SD/BCW 1.0 mm 1:16	2.59cdefg	1632.3d	4732.3a	58902.3a	9992.3a	0.58kl	3.53n	56.25b	519.95c
SD/BCW 2.0 mm 1:1	3.14abcde	983.3k	2203.3ij	20343.3q	4003.3q	1.03ghi	12.33h	12.35q	352.40hi
SD/BCW 2.0 mm 1:4	3.32ab	1532.3e	402.3m	36402.3f	7502.3f	1.23efg	1.26o	59.95a	182.25p
SD/BCW 2.0 mm 1:8	3.56a	1832.5a	412.5lm	29302.5j	4802.5m	0.70jk	11.65hi	45.80f	207.20o
SD/BCW 2.0 mm 1:16	2.83bcdef	733n	4603b	52503d	9453d	1.36def	6.30l	48.40e	401.20f
Control	3.09abcde	1287.5g	4587c	22090.0o	4070.0p	0.87i	19.25e	33.4i	260.60m

Mean with the same superscript along the same column are not significantly different ($p>0.05$)

*Amaranthuscruentus*obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The phosphorus content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly (P < 0.05) higher in plants that received SD/BCW (2.0 mm) 1:8 compostthan in plants that received RH/BCW (1.0 mm)1:8 compost. These phosphoruscontentswere higher than the contents in plants treated with the remaining composts. Phosphorus content obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.3 Potassium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The potassium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly (P < 0.05) higher in plants that received SD/BCW (1.0 mm) 1:16 compostthan plants treated with SD/BCW (2.0 mm) 1:16 compost. These potassium contents were higher than the contents in plants treated with RH/BCW (1.0 mm) 1:1 compost and RH/BCW (2.0 mm) 1:8 compost and the remaining compost treatments.The potassium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The potassium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly (P < 0.05) higher in plants that received SD/BCW (1.0 mm) 1:16 compostthan the plants treated with SD/BCW (2.0 mm) 1:16 compost.Thesepotassium contents were higher than thecontents in plants that received the remaining compost treatments.The potassium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.4 Calcium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The calcium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly (P < 0.05) higher in plants treated withRH/BCW (0.5 mm) 1:4 compostthan plants that received SD/BCW (1.0 mm) 1:16 compost.Calcium contentsin these plants were significantly (P < 0.05) higher than the contents in plants treated withthe remaining composts.Calcium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The calcium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly (P < 0.05) higher in plants fertilized with SD/BCW (1.0 mm) 1:16 compostthan plants grown on RH/BCW (0.5 mm) 1:4 compost.Thesecontentswere higher than the contents in plants treated with the remaining composts.Calcium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.5 Magnesium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The magnesium content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly (P < 0.05) higher in plants fertilized with SD/BCW (1.0 mm) 1:16 compostthan in plants that received RH/BCW (0.5 mm) 1:4 compost.Thesecontents were significantly (P < 0.05) higher than magnesium contents in plants that received the remaining compost treatments. However, the magnesium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The magnesium content in *Amaranthus* at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly (P < 0.05) higher in plants grown on SD/BCW(1.0 mm) 1:16 compostthan plants that received RH/BCW (0.5 mm)1:4 compost.These contents weresignificantly (P < 0.05) higherthan magnesium contentsin plants that received the rest of the compost treatments. Magnesium content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.6 Copper content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The copper content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly (P < 0.05) higher in plants amended withRH/BCW (1.0 mm) 1:4 compostthan in plants fertilized with RH/BCW (2.0 mm) 1:4 compost.However,these contents were not different fromcoppercontentsamended with some compost treatments but were higher than the contents in others. Coppercontent in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

In 2017 cropping season the copper content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) was significantly (P < 0.05) higher in plantstreated with RH/BCW(1.0 mm) 1:4 compostthan theplants treated with RH/BCW (2.0 mm) 1:4 compost.These contentswere higher than the contents in plants treated with other composts. The copper content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.7 Zinc content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

In 2016 cropping season the zinc content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) was significantly ($P < 0.05$) higher in plants grown on RH/BCW (2.0 mm) 1:1 compostthan plants grown on RH/BCW (2.0 mm) 1:4 compost.The zinc contents in these plants were higherthan the contents in plants treated with the rest of the composts. The zinc content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

In 2017 cropping season the zinc content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) was significantly ($P < 0.05$) higher in plants amended with RH/BCW (2.0 mm) 1:1 compostthan RH/BCW (2.0 mm) 1:4 compost.This content was higher than the content in plants treated with the remaining composts. The zinc content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.8 Manganese content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

The manganese content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 cropping season was significantly ($P < 0.05$) higher in plants that received SD/BCW (2.0 mm) 1:4 compostthan plants grown on SD/BCW (1.0 mm) 1:16 compost. Manganese contents inplants treated with these compostswerehigher than the contents in plants treated with the rest of the composts.The manganese content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The manganese content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly ($P < 0.05$) higher in plants amended with SD/BCW (2.0 mm) 1:4 compostthan plants treated with SD/BCW (1.0 mm) 1:16 compost.Thesecontentswere higher than the contents in plants treated with the remaining composts. Manganese content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

4.12.9 Iron content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2016 and 2017 seasons

In 2016 cropping season the iron content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) was significantly ($P < 0.05$) higher in plants treated with RH/BCW (2.0 mm) 1:8 compostthan plants grown on RH/BCW (2.0 mm) 1:1 compost.The iron contents in the listed composts werehigher than the contents in plants treated with the rest of the composts. The iron content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The iron content in *Amaranthuscruentus*at 9 weeks after transplanting (WAT) in 2017 cropping season was significantly ($P < 0.05$) higher in plants amended with RH/BCW (2.0 mm) 1:8 compostthan in plants amended with RH/BCW (2.0 mm) 1:1 compost.Theseiron contents werehigher than the contents in plants treated with the remaining composts. The iron content in *Amaranthuscruentus* obtained in the control was significantly higher than the contents in plants amended with some of the compost treatments.

The highest N, P, K, Ca, Mg and Mn contentsin *Amaranthus cruentus*were observed in plants treated with SD/BCW composts while Cu, Zn and Fe contents were high in plants treated with RH/BCW in the two cropping seasons. Plants treated with composts of different particle sizes also differed in nutrientsuptake in both cropping seasons.However, nutrients uptake in plants grown in the control was higher than the level of nutrients uptake in some treated plots. The results revealed that all the compost treatments recorded high mineral contents in all the treated plants. The result is in agreement with the report of previous researchers (Makinde *et al.*, 2010; Funda *et al.*, 2011; Mofunanya *et al.*,2012). The high contents of these nutrients could be attributed to their availability and release from the finished composts. The highest plant nutrients content under the compost treatments was observed in 2016 cropping season when irrigation was used. The low nutrient contents in plant tissue recorded in 2017 cropping season might have been attributed to the leaching of the nutrients by rain.*Amaranthuscruentus*is a sun loving plants, shorter period of sunlight in the rainy season reduced the growth rate of some crops, mostly the vegetables and adversely affected the build-up of nutrients in plant cells.

4.13 Post-experiment soil properties as influenced by compost types, particle sizes and composting ratios of the prepared composts in 2016 and 2017 cropping seasons

The effects of compost types, particle sizes and composting ratios of the prepared composts on somephysical properties of the experimental soils used in 2016 and 2017 cropping seasons are presented in Table 14.

4.13.1 Sand content of the experimental soils used in 2016 and 2017 cropping seasons

The sand content of the experimental soils used in 2016 season was not significantly ($P < 0.05$) different in soils treated with SD/BCW (2.0 mm)1:1 compostand SD/BCW

TABLE 14
Particle sizes distribution of the experimental soilsused in 2016 and 2017 seasons as influenced by the applied compost treatments

Treatment	2016 Sand (gkg^{-1})	2016 Silt (gkg^{-1})	2016 Clay (gkg^{-1})	2016 Textural Class	2017 Sand (gkg^{-1})	2017 Silt (gkg^{-1})	2017 Clay (gkg^{-1})	2017 Textural Class
RH/BCW 0.5 mm 1:1	861.65hg	32.5cdefg	105.85c	loamy sand	866.85gh	29.9cdefg	103.25c	loamy sand
RH/BCW 0.5 mm 1:4	862.65gh	49.9b	87.45efg	loamy sand	867.85fg	47.3b	84.85efg	loamy sand
RH/BCW 0.5 mm 1:8	880.25e	33.3cde	86.45hg	loamy sand	885.45e	30.7cde	83.85gh	loamy sand
RH/BCW 0.5 mm 1:16	880.75cde	32.3defg	86.95fgh	loamy sand	885.95cde	29.7defg	84.35fgh	loamy sand
RH/BCW 1.0 mm 1:1	861.5hi	50.8b	87.7efg	loamy sand	866.7hg	48.2b	85.1efg	loamy sand
RH/BCW 1.0 mm 1:4	880.75cde	32.3defg	86.95fgh	loamy sand	885.95cde	29.7defg	84.35fgh	loamy sand
RH/BCW 1.0 mm 1:8	859.75j	54.3a	85.95h	loamy sand	864.95j	51.7a	83.35h	loamy sand
RH/BCW 1.0 mm 1:16	860.25ij	33.3cde	106.45bc	loamy sand	865.45ij	30.7cde	103.85bc	loamy sand
RH/BCW 2.0 mm 1:1	863.05g	33.1cdef	103.85d	loamy sand	868.25f	30.5cdef	101.25d	loamy sand
RH/BCW 2.0 mm 1:4	882.05abc	35.1d	82.85i	loamy sand	887.25abc	32.5cd	80.25i	loamy sand
RH/BCW 2.0 mm 1:8	882.3ab	34.6cd	83.1i	loamy sand	887.5ab	32cd	80.5i	loamy sand
RH/BCW 2.0 mm 1:16	862.8gh	33.6cde	103.6d	loamy sand	868fg	31cde	101d	loamy sand
SD/BCW 0.5 mm 1:1	860.65h	31.9defg	107.45ab	loamy sand	865.85hij	29.3defgh	104.85ab	loamy sand
SD/BCW 0.5 mm 1:4	861.65hg	29.9hg	108.45a	loamy sand	866.85gh	27.3hg	105.85a	loamy sand
SD/BCW 0.5 mm 1:8	880.65de	31.9defg	87.45efg	loamy sand	885.85de	29.3defgh	84.85efg	loamy sand
SD/BCW 0.5 mm 1:16	881.15bcde	30.9efgh	87.95ef	loamy sand	886.35bcde	28.3efgh	85.35ef	loamy sand
SD/BCW 1.0 mm 1:1	881.9abcd	29.4h	88.7e	loamy sand	887.1abcd	26.8h	86.1e	loamy sand
SD/BCW 1.0 mm 1:4	881.15bcde	30.9efgh	87.95ef	loamy sand	886.35bcde	28.3efgh	85.35ef	loamy sand
SD/BCW 1.0 mm 1:8	860.15ij	32.9cdef	106.95bc	loamy sand	865.35ij	30.3cdef	104.35bc	loamy sand
SD/BCW 1.0 mm 1:16	881.65abcd	32.5cdef	85.85h	loamy sand	886.85abcd	29.9cdefg	83.25h	loamy sand
SD/BCW 2.0 mm 1:1	882.65a	30.5fgh	86.85fgh	loamy sand	887.85a	27.9efg	84.25fgh	loamy sand
SD/BCW 2.0 mm 1:4	881.65abcd	32.5cdefg	85.85h	loamy sand	866.85gh	29.9dce	103.25c	loamy sand
SD/BCW 2.0 mm 1:8	882.3ab	34.6cd	83.1i	loamy sand	867.1fgh	29.4defgh	103.5bc	loamy sand
SD/BCW 2.0 mm 1:16	862.4gh	31efgh	106.6bc	loamy sand	867.6fg	28.4efgh	104bc	loamy sand
Control	878.4f	36.4c	85.3h	loamy sand	883.7e	33.7c	82.6h	loamy sand

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

The sand content of the experimental soils used in 2017 season was not significantly ($P < 0.05$) different in soils treated with SD/BCW (2.0 mm) 1:1 compost and RH/BCW (2.0 mm) 1:8 compost.These sand contents were not statistically different from its contents in soils treated with some of the composts but were higher in others. The sand content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

4.13.2 Silt content of the experimental soils used in 2016 and 2017 cropping seasons

The silt content of the experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soil treated with RH/BCW (1.0 mm) 1:8 compost than in soils treated with RH/BCW (1.0 mm) 1:1 compost and RH/BCW (0.5 mm) 1:4 compost which were not significantly different. These silt contents were not statistically different from its contents in soils treated with some of the composts but were higher in others. The silt content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

The silt content of the experimental soils used in 2017season was significantly ($P < 0.05$) higher in soil treated with RH/BCW (1.0 mm) 1:8 compostthan in soil treated with RH/BCW (1.0 mm) 1:1 compost.These silt contents were not statistically different from its contents in soils treated with some of the composts but were higher in others. The silt content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

4.13.3 Clay content of the experimental soils used in 2016 and 2017 cropping seasons

The clay content of the experimental soils used in 2016 season was not significantly ($P < 0.05$) different in soil treated with SD/BCW (0.5 mm) 1:4 compost andSD/BCW

(0.5 mm) 1:1 compost.But these were higher thanthe clay content in soil treated with SD/BCW (1.0 mm) 1:8 compost.These clay contents were not statistically different from its contents in soils treated with some of the composts but were higher in others. The lowest claycontent was obtained in the control.

The clay content of the experimental soils used in 2017 season did not significantly (P < 0.05) different in soil treated with SD/BCW (0.5 mm) 1:4 compost and SD/BCW (0.5 mm) 1:1 compost.But these contents were higher than clay content in soil treated with SD/BCW (1.0 mm) 1:8 compost.These clay contents were not statistically different from its contents in soils treated with some of the composts but were higher in others. The clay content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

The effects of compost types, particle sizes and composting ratios of the prepared composts on chemical properties of the experimental soils used in 2016 and 2017 cropping seasons are presented in Tables 15 and 16.

4.13.4 pH content of the experimental soils used in 2016 and 2017 cropping seasons

The pHvalueof the experimental soils used in 2016 season was not significantly (P < 0.05) different in soils treated with RH/BCW (2.0 mm)1:1 compost,SD/BCW (0.5 mm) 1:16 compostand SD/BCW (1.0 mm) 1:1 compost.But these pH values were higher than the valuesin soils treated with the remaining composts.

TABLE 15

Chemical properties of experimental soils used in 2016 season at harvesting of *Amaranthus cruentus as* affected by applied compost treatments

Treatment	pH	EC	OC	TN	P	Ca	Mg	K	Na	Cu	Zn	Fe	Mn
		(dS/m)	(g/kg)	(g/kg)	(mg/kg)	→	(cmol/kg)	←		→	(mgkg^{-1})	←	
RH/BCW 0.5 mm 1:1	5.825j	0.106h	14.725k	0.9ghij	0.7c	828.1k	395.5e	5.3a	10.8a	1.27j	9.39d	11.97x	19.87l
RH/BCW 0.5 mm 1:4	6.125defg	0.087m	17.6b	1.2a	0.8b	956.1g	89.5g	3.1g	9.7cd	2.81d	2.39k	45.85e	24.45f
RH/BCW 0.5 mm 1:8	6.125defg	0.101jk	16.7cde	1.1abcde	0.7c	787.3l	59.7jkl	3.5e	6.4hg	0.29l	1.21o	12.81w	25.87b
RH/BCW 0.5 mm 1:16	6.175de	0.110fg	15.225ij	1.1abc	0.7c	931.5h	54.3klm	3gh	7.1f	3.08c	3.92i	40.72j	25.56c
RH/BCW 1.0 mm 1:1	6.05efgh	0.075p	17.25cb	1.2a	0.8b	603r	318.2f	2.6l	6.3hg	2.47e	9.79b	13.19v	19.27n
RH/BCW 1.0 mm 1:4	5.975hi	0.083n	14.875jk	1defg	0.8b	764.7m	66.5hijk	2.2no	5.4ij	2d	3.8i	13.92t	25.16d
RH/BCW 1.0 mm 1:8	5.875ij	0.076p	16.05fg	0.9fghi	0.7c	1082.7c	54.1klm	4.1d	9.5cd	3.9a	4.64h	35.1m	17.86r
RH/BCW 1.0 mm 1:16	6.225ed	0.202a	10.88p	0.7kl	0.7c	893.7i	78.1gh	3ghi	9.6cd	0.81k	9.53c	13.51u	17.15t
RH/BCW 2.0 mm 1:1	6.525a	0.078o	12no	1bcdef	1.1a	7309o	67.7hijk	2.8jk	10.4bc	2.81d	9.55c	62.87c	15.69u
RH/BCW 2.0 mm 1:4	6.025efgh	0.136c	15.88fgh	0.9fghi	0.7c	750.5n	67.5hijk	3.2f	9.9bc	2.01g	1.35n	28.71r	18.17q
RH/BCW 2.0 mm 1:8	6.05efgh	0.139b	15.65ghi	0.9efghi	0.7c	762.2mn	45.8m	4.5c	8.1e	4.01a	2.79j	49.49d	23.57g
RH/BCW 2.0 mm 1:16	6ghi	0.104i	16.3def	1cdefg	0.8b	873.2j	438.8d	4.9b	10.5a	1.88g	2.8j	30.02o	18.86p
SD/BCW 0.5 mm 1:1	6.025fgh	0.082n	13.7l	0.9ghij	0.7c	1065.5d	64.5hijk	2p	9.6cd	1.47i	9.89b	37.67k	19.07o
SD/BCW 0.5 mm 1:4	6.325bc	0.109g	15.7ghi	1.1abcde	0.9abc	685.3p	74.7hi	2.1o	6.5g	2.95c	2.77j	45.61f	21.31j
SD/BCW 0.5 mm 1:8	6.325bc	0.100k	12.6mn	0.8hij	0.9abc	867.3j	67.7hijk	2.3mn	5.2j	2.25f	1.99m	33.19n	22.71h
SD/BCW 0.5 mm 1:16	6.475a	0.111f	11.9o	0.8ijk	0.9abc	639.5q	62.3ijk	3hg	9.1d	1.72h	2.18l	37.2l	28.52a
SD/BCW 1.0 mm 1:1	6.45ab	0.079o	13.15lm	1cdefg	1.1a	611.8r	73.8hi	2.7kl	8.2e	2.73d	8.37f	81.31b	18.19q
SD/BCW 1.0 mm 1:4	5.975hi	0.102j	15.4hij	1defg	0.7c	1156.5b	595.9a	2.9hij	7.4f	1.62h	9.06e	29.2q	22.76h
SD/BCW 1.0 mm 1:8	5.875ij	0.082n	12.25no	0.7kl	0.7c	1042.3e	47.3lm	1.7q	5.9hi	2.76d	2.86j	42.9h	22.42i
SD/BCW 1.0 mm 1:16	6.225cd	0.130d	8.4q	0.6l	0.9abc	1183.7a	471.7c	2.8ijk	8.4e	2.49e	9.47cd	29.47p	24.59e
SD/BCW 2.0 mm 1:1	6.225cd	0.113e	16.2efg	1.1abcd	1ab	996.5f	512.9b	2.4m	9.4cd	1.25j	11.25a	24.61s	17.61s
SD/BCW 2.0 mm 1:4	6.125defg	0.082n	16.875cd	0.9efgh	0.8b	898.9i	46.7lm	2.8ijk	9.9bc	3.53b	5.23g	45.15g	13.97v
SD/BCW 2.0 mm 1:8	6.16def	0.091l	14.75k	1defg	0.9abc	907.4i	71.8hij	3.5e	6.1gh	2.49e	2.11l	85.49a	19.49m
SD/BCW 2.0 mm 1:16	6.23cd	0.082n	18.4a	1.1ab	0.9abc	1002.4f	73.6hi	1.9q	9.1d	2.38ef	4.66h	42.62i	20.02k
Control	4.43k	0.075p	12.55mn	0.65kl	0.44d	1.04s	0.11n	0.11r	0.29k	1.48i	1.06p	11.26y	11.77w

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

TABLE 16

Chemical properties of experimental soils used in 2017 season at harvesting of *Amaranthus cruentus* as affected by applied compost treatments

Treatment	pH	EC (dS/m)	OC (g/kg)	TN (g/kg)	P (mg/kg)	Ca →	Mg (cmol/kg)	K ←	Na	Cu →	Zn ($mgkg^{-1}$)	Fe ←	Mn
RH/BCW 0.5 mm 1:1	5.4bcd	0.13d	12.33g	0.77ghij	0.85hij	945.5h	435.5c	6.37a	8.85a	1.765h	8.25c	11.07v	16.53l
RH/BCW 0.5 mm 1:4	5.3cdef	0.11e	15.2a	1.03ab	0.99edfg	991.5f	100.5e	4.15f	7.3cd	2.825cd	1.39o	33.93j	21.43e
RH/BCW 0.5 mm 1:8	5.5b	0.13d	14.6abc	0.98abcde	0.86ghij	874.5k	64.5ij	4.58e	4.5ijk	1.025k	1.23p	14.85s	23.63b
RH/BCW 0.5 mm 1:16	5.3ef	0.13d	13.53de	1.01abc	0.83ij	960.5g	66.5hij	3.82ij	5.15gh	3.235b	2.72k	30.28l	22.44d
RH/BCW 1.0 mm 1:1	5.5bc	0.10f	13.55de	0.98abc	0.99defg	811m	376d	3.71j	5.25gh	2.69de	8.61b	12.11u	15.89m
RH/BCW 1.0 mm 1:4	5.4cde	0.10f	12.68fg	0.9bcdefgh	0.88ghij	877.5k	77.5fghi	3.26l	4.28jk	2.115g	2.5l	15.56r	22.88c
RH/BCW 1.0 mm 1:8	5.3ef	0.11e	14.05cd	0.8ghijk	0.75j	1048.5b	65.5ij	5.06d	6.15e	4.015a	3.42j	32.46k	15.62n
RH/BCW 1.0 mm 1:16	5.5b	0.22a	11.28h	0.73jk	0.84ij	937.5h	88.5ef	3.76j	7.38cd	0.905k	7.43e	12.57t	14.93o
RH/BCW 2.0 mm 1:1	5.5b	0.10f	11h	0.85defghi	1.18abc	780.5n	74.5ghi	3.91hi	8.2b	2.925c	8.53b	50.99c	14.51p
RH/BCW 2.0 mm 1:4	5.4bcd	0.15c	13.58de	0.83fghijk	0.9ghi	856.5l	79.5fgh	4.03fgh	7.58c	2.105g	0.35q	26.63o	15.87m
RH/BCW 2.0 mm 1:8	5.4cdef	0.16b	13.65de	0.84fghijk	0.94efghi	871k	57j	5.55c	5.85ef	4.07a	1.85m	36.45f	21.47h
RH/BCW 2.0 mm 1:16	5.4f	0.13d	14.3bc	0.91bcdef	0.88ghij	900j	530b	5.72b	7.24cd	2.12g	1.68n	26.84n	16.74k
SD/BCW 0.5 mm 1:1	5.2f	0.10f	11.43h	0.78ghijk	0.86ghij	1044.5bc	82.5fg	3.11m	7.33cd	1.825h	7.51de	28.85m	16.89j
SD/BCW 0.5 mm 1:4	5.4bcd	0.13d	13.5de	0.99abc	1.21a	800.5m	90.5ef	3.25l	5.1gh	2.905c	1.59n	37.53d	20.05h
SD/BCW 0.5 mm 1:8	5.5b	0.11e	12.2g	0.78ghijk	1.06bcde	982.5f	80.5fg	3.37l	4k	2.445f	1.45o	34.81h	20.47fg
SD/BCW 0.5 mm 1:16	5.8a	0.1f	11.33h	0.85defghij	1.04def	747.5o	72.5ghi	4.1fg	7.16cd	1.875h	1.7n	34.98g	24.46a
SD/BCW 1.0 mm 1:1	5.5bc	0.10f	12.35g	0.93bcdef	1.19ab	921i	84fg	3.81ij	5.95e	2.35f	6.35g	72.59a	15.79m
SD/BCW 1.0 mm 1:4	5.4cde	0.12d	13.18ef	0.9bcdefgh	0.92fghi	1007.5e	612.5a	4gh	5.28fg	2.015g	6.7f	26.68o	20.58f
SD/BCW 1.0 mm 1:8	5.3ef	0.10f	11.15h	0.71k	0.76j	1039.5bcd	57.5j	2.84n	4.65hij	2.815cd	1.86m	36.78e	20.34g
SD/BCW 1.0 mm 1:16	5.4bcd	0.16b	9.82j	0.75ijk	1.05cdef	1222.5a	523.5b	3.93hi	6.18e	2.665e	7.63d	25.59p	20.35g
SD/BCW 2.0 mm 1:1	5.5b	0.13d	14cd	0.97abcde	1.11abcd	1034.5cd	536.5b	3.51k	7.2cd	1.405j	9.47a	20.47q	16.47l
SD/BCW 2.0 mm 1:4	5.3cdef	0.11e	14.78ab	0.88cdefghi	0.95efghi	1014.5e	57.5j	3.93hi	7.58c	3.345b	4.43h	34.23i	11.69q
SD/BCW 2.0 mm 1:8	5.5b	0.11e	12.55g	0.87cdefghi	0.99defg	933hi	78fghi	4.61e	4.85ghi	2.67e	1.33op	66.71b	17.37i
SD/BCW 2.0 mm 1:16	5.3def	0.10f	15a	1.07a	0.98defgh	1030d	84fg	2.9n	6.9d	2.46f	3.58i	34.72h	16.8jk
Control	4.95g	0.096g	10.35i	0.55l	0.35k	1.32p	0.15k	0.14o	0.19l	1.60i	1.09q	10.33w	10.57r

Mean with the same superscript along the same column are not significantly different ($p < 0.05$)

The lowest pH value was obtained in the control plot in 2016 season.

The pHvalueof the experimental soils used in 2017 season was significantly (P < 0.05) higher in soil treated with SD/BCW (0.5 mm) 1:16 compostthan in soil amended with SD/BCW (2.0 mm) 1:1and 1:8 composts.Thess pH values did not differ from the pH value in soils treated with some compost but was higher than values in other compost treatments. The lowest pH valuewas obtained in soil without amendment (control) in 2017 season.

4.13.5 Electrical conductivity of the experimental soils used in 2016 and 2017 cropping seasons

The ECof the experimental soil used in 2016 season was significantly (P < 0.05) higher in soil treated with RH/BCW (1.0 mm) 1:16 compost than in soil treated with RH/BCW (2.0 mm) 1:8 compost.These EC values were significantly higher than values obtained in soils treated withthe remaining composts. The least value was obtained in the control in 2016 season.

The ECof the experimental soils used in 2017 season was significantly (P < 0.05) higher in soil treated with RH/BCW(1.0 mm) 1:16 compost than in soil treated with SD/BCW (1.0 mm) 1:16 compost.But this EC value was not significantly different from the value obtained in soil treated with RH/BCW (2.0 mm) 1:8 compost.Thesevalueswere significantly (P < 0.05) higher than values in soils treated with the rest of the compost treatments. The least value was obtained in the control in 2017 season.

4.13.6 Organic carbon content of the experimental soils used in 2016 and 2017 cropping seasons

The organic carboncontentof the experimental soils used in 2016 season was significantly (P < 0.05) higher in soils treated with SD/BCW (2.0 mm) 1:16

compostthan in soil treated with RH/BCW (0.5 mm) 1:4 compost.Thesevalues were higher than the contents in soils treated with the remaining composts. However, the organic carbon contents in soils treated with some of the remaining composts were not statistically different from its contents in soils treated with others. The organic carbon content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

The organic carboncontentof the experimental soils used in 2017 season was not significantly ($P < 0.05$) different in soil treated with RH/BCW (0.5 mm)1:4 compostand SD/BCW (2.0 mm) 1:16 and 1:4 composts.These contents were higher than the contents in soils treated with the remaining composts. But the organic carbon contents in soils treated with some of the remaining composts were not statistically different from its contents in soils treated with others. Moreover, organic carbon content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments.

4.13.7 Total nitrogen content of the experimental soils used in 2016 and 2017 cropping seasons

The total nitrogencontentof the experimental soils used in 2016 season not was significantly ($P < 0.05$) different in soil treated with RH/BCW (0.5 mm) 1:4 compostand RH/BCW (1.0 mm) 1:1 compost.These contents were not different from the contentsin soil amended with some compost treatments but higher than the contents in others.The total nitrogen content obtained in the control was significantly higher than the contents in soils amended with some of the compost treatments in 2016 season.

The total nitrogencontentof the experimental soils used in 2017 season was not significantly ($P < 0.05$) different in soils treated with SD/BCW (2.0 mm) 1:16 and 1:1

compostsandRH/BCW (0.5 mm) 1:4 compost.These contents were not different from the contents in soil amended with some compost treatments but higher than the contents in others. The total nitrogen content obtained in the control was the least in 2017 season.

4.13.8 Phosphorus contents of the experimental soils used in 2016 and 2017 cropping seasons

The phosphoruscontentof the experimental soils used in 2016 season was not significantly different in soils treated with RH/BCW (2.0 mm) 1:1 compost and SD/BCW (1.0 mm) 1:1 and 1:16 composts.These contents were not different from the contents in soil amended with some compost treatments but higher than the contents in others. The lowest phosphorus content was obtained in the control in 2016 season.

The phosphoruscontentsof the experimental soils used in 2017 season werenot significantly ($P < 0.05$) different in soils treated with SD/BCW (0.5 mm) 1:4 compostand SD/BCW (1.0 mm) 1:1 compost.These contents were not different from the contents in soil amended with some compost treatments but higher than the contents in others. The phosphorus content obtained in the control was the least in 2017 season.

4.13.9 Calcium content of the experimental soils used in 2016 and 2017 cropping seasons

The calciumcontentof the experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soils treated with SD/BCW (1.0 mm) 1:16 compost than in soil treated with SD/BCW (1.0 mm) 1:4 compost.Thesevalues werehigher than the valuesin soils treated with the remaining composts. The lowest value was obtained in the control in 2016 season.

The calciumcontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soils treated with SD/BCW (1.0 mm) 1:16 compost than in soils treated with RH/BCW (1.0 mm) 1:8 compost.This calcium contents was not significantly different from the contents in soils treated with SD/BCW (1.0 mm) 1:8 compostand SD/BCW (0.5 mm) 1:1 compost.These values were higher than the values in soils treated with the remaining composts. The lowest value was obtained in the control in 2017 season.

4.13.10 Magnesium content of the experimental soils used in 2016 and 2017 cropping seasons

The magnesiumcontentofthe experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soils treated with SD/BCW (1.0 mm) 1:4 compostthan in soil treated with SD/BCW (2.0 mm) 1:1 compost.These values were higher than the values in soils treated with the remaining composts. The lowest value was obtained in the control in 2016 season.

The magnesiumcontentofthe experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soils treated with SD/BCW (1.0 mm) 1:4 compost than in soil treated with SD/BCW (2.0 mm) 1:1 compost.This magnesium content was not different from the contents in soils treated with RH/BCW (2.0 mm) 1:16 compost and SD/BCW (1.0 mm) 1:16 compost.These values were higher than the values in soils treated with the remaining composts. The lowest value was obtained in the control in 2017 season.

4.13.11 Potassium content of the experimental soils used in 2016 and 2017 cropping seasons

The potassiumcontentof the experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soil treated with RH/BCW (0.5 mm) 1:1 compost than in soil treated with RH/BCW (2.0 mm) 1:16 compost.These contentswerehigher than the contentsin soils treated with the rest of the compost treatments. The lowest content was obtained in the control in 2016 season.

The potassiumcontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soil treated with RH/BCW (0.5 mm) 1:1 compost than in soil treated with RH/BCW (2.0 mm) 1:16 compost.These contents were higher than the contents in soils treated with the rest of the compost treatments. The lowest content was obtained in the control in 2017 season.

4.13.12 Sodium content of the experimental soils used in 2016 and 2017 cropping seasons

The sodiumcontentof the experimental soils used in 2016 season was not significantly ($P < 0.05$) different in soils treated with RH/BCW (0.5 mm) 1:1 compost and RH/BCW (2.0 mm) 1:16 compost.But these sodium contentswere higher than the contentsin soils treated with the remaining composts. However, the contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2016 season.

The sodiumcontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soil treated with RH/BCW (0.5 mm) 1:1 compost than in soil treated with RH/BCW (2.0 mm) 1:1 compost.These sodium contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2017 season.

4.13.13 Copper content of the experimental soils used in 2016 and 2017 cropping seasons

The coppercontentof the experimental soils used in 2016 season was not significantly ($P < 0.05$) differentin soils treated with RH/BCW (2.0mm) 1:8 compost and RH/BCW (1.0 mm) 1:8 compost.But these contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. However, copper content in the control was higher than the contents in some treated plots in 2016 season.

The coppercontentof the experimental soils used in 2017 season was not significantly ($P < 0.05$) different in soil treated with RH/BCW (2.0 mm) 1:8 compost and RH/BCW (1.0 mm) 1:8 compost.But these contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. The copper content in the control was higher than the contents in some treated plots in 2017 season.

4.13.14 Zinc content of the experimental soils used in 2016 and 2017 cropping seasons

The zinccontentof the experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (2.0 mm) 1:1 compost than in soils treated with SD/BCW (0.5 mm) 1:1 compost and RH/BCW (1.0 mm) 1:1 compost.These contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. The lowest zinc content was obtained in the control in 2016 season.

The zinccontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (2.0 mm) 1:1 compost than in soils treated with RH/BCW (1.0 mm) 1:1 compost and RH/BCW (2.0 mm) 1:1 compost.These contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. However, zinc content in the control was higher than the content in plots treated with RH/BCW (2.0 mm)1:4 compost in 2017 season.

4.13.15 Iron content of the experimental soils used in 2016 and 2017 cropping seasons

The ironcontentof the experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (2.0 mm) 1:8 compost thanin soil treated with SD/BCW (1.0 mm) 1:1 compost.But these iron contents were higher than the contents in soils treated with the remaining composts. However, the contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2016 season.

The ironcontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (1.0 mm) 1:1 compost than soil amended with SD/BCW (2.0 mm) 1:8 compost. These iron contents were higher than the contents in soils treated with the remaining composts. However, the contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2017 season.

.4.13.16 Manganese content of the experimental soils used in 2016 and 2017 cropping seasons

The manganesecontentofthe experimental soils used in 2016 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (0.5 mm) 1:16 compost than in soil treated withRH/BCW (0.5mm) 1:8 compost. These contents were higher than the contents in soils treated with the remaining composts. The contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2016 season.

Manganesecontentof the experimental soils used in 2017 season was significantly ($P < 0.05$) higher in soil treated with SD/BCW (0.5 mm) 1:16 compost than in soil treated with RH/BCW (0.5 mm) 1:8 compost.But these manganese contents were higher than the contents in soils treated with the remaining composts. However, the contents in some of the remaining treated soils did not differ. The lowest content was obtained in the control in 2017 season.

The texture of the post-planting soil was loamy sand. Application of compost treatments had significant changes in the different particle sizes distribution. The percentage sand was significantly altered by the addition of composts to the experimental plots. The sand fraction in all the plots decreased while the clay and silt fractions increased interchangeably in 2016 season. However, sand fraction increased in some experimental plots while silt and clay fractions reduced interchangeably in some experimental plots in 2017 season. Nevertheless, the textural class of all the experimental plots in 2016 and 2017 trials was not affected by the application of compost treatments which concurred the report of Brady and Weil (2002) who pointed out that management practices do not affect the textural class of the soil rather the texture of the soil can only be changed by mixing it with a soil of different textural class. The textural class of the post-planting soil remaining as it was before the application of various treatments confirms the report of Onwudike *et al.*, (2015), whostated that addition of organic matter to the soil did not alter the textural class of the soil.

The pH of the experimental soils used in the study ranged from 4.43 – 6.52 in 2016 season and 4.95 – 5.80 in 2017 season with significantly($P < 0.05$) higher pH values in soils treated with various compostscompare to the control (without amendment) in the two cropping seasons. The pH valuesin the control were 4.43 and 4.95 in 2016 and 2017 seasons, respectively, which were at strongly acidic range as recorded in the pre-plantingsoil report. Application of various compost treatments increased the pH of thepost-planting soils to acidic and near neutral rangewhich is in line with the report of Orhue *et al.* (2014). The increase in the pH of the experimental soil of Obio Akpa, Oruk Anam in Akwa Ibom State with the application of the compost treatments was enhanced by the contents of the various composts as was reported by Haute (2014) that compost application significantly increased soil pH and the contents of N, P, K, Ca, Mg and Na in the topsoil. Organic amendments can increase the pH of acidic soils (Whalen *et al.,* 2000) thereby improving availability of macronutrients while reducing the solubility of Al^{3+} and Mn^{2+} ions. Plots treated with SD/BCW and RH/BCW composts had higher pH values than the control in both seasons. Nevertheless, the pH values of the experimental plots in 2016 (dry season)trial were higher than the values in 2017 (rainy season) trial. This might result from the effect of leaching of basic cations by rainfall experienced in 2017 season.

The electrical conductivity (EC) ranged from 0.075 – 0.202dSm^{-1} in 2016 season and 0.096 – 0.220 dSm^{-1} in 2017 season which were higher than the value (0.05 dSm^{-1})obtained in the pre-planting soil report, indicating availability of basic cations in the adsorption complex of the soil and this confirm the report of Wapa *et al.* (2013).

The organic carbon content of the post-planting soil ranged from 8.4 – 18.4g/kg in 2016 season and 9.82 -15.20 g/kg in 2017 cropping season, respectively, which were significantly($P < 0.05$) lower than the content(27.73 g/kg)obtained in the pre-planting soil report. The decrease in organic carbon content of the soil may be attributed to the rate of mineralization of the organic fertilizer by soil microorganisms.

The nitrogen and phosphorus contents of the post-planting soils were lower than values obtained in the pre-planting soilreport. The low contents of nitrogen and phosphorus in the post-planting soil may be attributed to plant uptake and microbial assimilation. Moreover, low pH of 5.0 or below according to Osemwota (2010) can lead to P fixation by Fe and Al oxides content of the soil.

Calciumcontentsin the post-planting soilsweresignificantly ($P < 0.05$) higherin all the treated soils in 2016 (603.0 – 1183.7 cmol/kg) and 2017 (747.5 – 1225.5 cmol/kg) seasons.However, calcium content was low in the control (1.04 cmolkg^{-1}) in 2016 seasonbut higher (1.32 cmol/kg) in the control in 2017 season compare to its content (1.20 cmolkg^{-1})in the pre-planting soil report.

Magnesium contentswere significantly ($P < 0.05$) higherin all the treated soils in 2016season (45.8 – 595.9 cmol/kg) and (57.5 – 612.5 cmol/kg) in 2017season.However, magnesium contents werelow in the control (0.11 cmolkg^{-1}) in 2016 season (0.15 cmol/kg) in control in 2017 compare to the content (1.12 cmolkg^{-1}) obtained in pre-planting soil report.

The potassium contentswere significantly ($P < 0.05$) higherin all the treated soils in 2016 season (1.9 –5.3 cmol/kg) and(0.84 – 6.37 cmol/kg) in 2017season.However, its contents werelow in the control (0.11 and 0.14 cmolkg^{-1}) in 2016 and 2017 seasons,respectively, compare to the content (0.17 $cmolkg^{-1}$) obtained in pre-planting soil report.

The sodium contentswere significantly (P < 0.05) higherin all the treated soils in 2016 season (5.20 – 10.8 cmol/kg) and(4.28 – 8.85 cmol/kg) in 2017season and in the control (0.29 and 0.19 $cmolkg^{-1}$) in 2016 and 2017 seasons, respectively, compare to the content (0.05 $cmolkg^{-1}$) obtained in pre-planting soil report.

These exchangeable bases increased with the addition of organic materials to the soil. Theincrease in exchangeable cations in all amended soils is in line with the findings of Onwudike *et al.* (2015) who observed significant increase in exchangeable cations when 10 t/ha rice mill waste plus 12 t/ha poultry manure was applied to the soil.

Copper contentswere significantly (P < 0.05) higherin all the treated soils in 2016 and 2017 seasonsand in the control in 2017 season but it was lower in the control in 2016 season than the content obtained in pre-planting soil report. Zinccontents weresignificantly (P < 0.05) higher in soils treated with RH/BCW 0.5 mm 1:1, RH/BCW 1.0 mm 1:1, RH/BCW 1.0 mm 1:16, RH/BCW 2.0 mm 1:1, SD/BCW 0.5 mm 1:1, SD/BCW 1.0 mm 1:1, SD/BCW 1.0 mm 1:4, SD/BCW 1.0 mm 1:16and SD/BCW 2.0 mm 1:1in 2016 and 2017 seasons compare to the content (5.90 mg/kg) in the pre-planting soil. Iron contents were significantly (P < 0.05) lowerin all the treated soils and the control in 2016 and 2017 seasonscompare to the content (170.4 mg/kg) in pre-planting soil report. Manganese contents were significantly (P < 0.05) higherin all the treated soils and the control in 2016 and 2017 seasonscompare to the value (2.45 mg/kg) obtained in pre-planting soil report. The decrease in some micronutrients content in some of the post-plantingsoils may be attributed to the formation of metal-organic matter complexes between the micronutrients and the composts in the soil culminating to reduction of the micronutrients in the soil.

The carbon to nitrogen (C/N) ratio of the post-plantingsoils ranged from 12: 1 – 19: 1 in both seasons which were at the level of mineralization. The C/N ratios of the amended soils were significantly($P < 0.05$) lower than the C/Nratio (23:1) obtained in the pre-planting soil. The influence of applied compost treatments on the C/N ratio of the post-planting soil is attributed to the quality of the finished composts. Onwudike *et al.* (2015) reported that rice mill waste with C/N ratio of 28:1 combined with poultry manure decreased the C/N ratio of post-planting soil than sawdust with C/N ratio of 71:1 combined with the same poultry manure.

The applied compost treatments showed significant changes in the C/N ratio of the post-planting soil. The decrease in the C/N ratio of the post-planting soil (12:1 – 19:1) relative to the C/N ratio (23:1) of pre-planting soil may be attributed to the C/N ratio (14:1 – 22:1) of the finished composts applied to the soil, and the rate of mineralization of composts by soil organisms in the soil. Onwudike *et al.* (2015) reported that rice mill waste with C/N ratio of 28:1 combined with poultry manure decreased the C/N ratio of post-planting soil than sawdust with C/N ratio of 71:1 combined with the same poultry manure. Generally, the chemical properties of the post-plantingsoil in both seasons were higher than the properties obtained in pre-planting soil report. Hence, it was observed that the compost treatments had positive influence on the inherent properties of the soil as confirmed by Oladipo, *et al.* (2005)

that organic wastes contain essential nutrients needed for improvement of soil fertility, plant growth and yield.

Composting of organic resources with lower C/N ratios encouraged rapid decomposition of the materials and improved the quality of the end-product. Decrease in C/N ratio with composting time was reported by Ogunwande (2011) and attributed to either the mineralization of the substrates present in the initial composting materials or an increase in total N content resulting from the concentration effect as carbon is biodegraded. Composts with final C/N ratio less than 25:1 showed an indication of maturity (Bernal *et al*., 2009). Organic materials with small particle sizes expose a wider surface area for faster decomposition than those with large surface areas. The more the available surface area of organic materials (Insam and de Bertoldi, 2007) the higher the rate of decomposition of the materials by microorganisms because most of the activity occurs at the interface of particle size. Application of composts with small particle size was ideal during the 2016 cropping season whereas those with large particle size were effective during the 2017 season as such applications encouraged steady and slow release of nutrients that could not be easily leached by heavy rainfall experienced within the period. This indicated that this soil needs selective application of composts with different particle sizes to suit each cropping season and other management practices for sustainable *Amaranthus* production.

4.14 Yield of *Amaranthus cruentus* as influenced by different compost treatments in 2016 and 2017 seasons

The effects of compost types, particle sizes and composting ratios of the prepared compostson the fresh leaf yield of *Amaranthuscruentus*taken in 2016 and 2017 cropping seasons are presented in Table 17.

4.14.1 Effects of compost types, particle sizes and composting ratios of the prepared composts on the fresh leaf yield of *Amaranthuscruentus* in 2016 and 2017 cropping seasons

The fresh leaf yield of*Amaranthus cruentus*in 2016 season was significantly (P < 0.05) higher in plants fertilized with RH/BCW (0.5 mm) 1:1 compost than in plants grown on SD/BCW (2.0 mm) 1:16 compost.*Amaranthus cruentus*with the highest fresh leaf yield was obtained in plants fertilized with RH/BCW (0.5 mm) 1:1 compost (Plate 7). The fresh leaf yield of *Amaranthus cruentus* fertilized with SD/BCW (2.0 mm) 1:16 compost was significantly higher than the yield of plants fertilized with SD/BCW (1.0 mm) 1:16 compost. The yield of *Amaranthus cruentus* fertilized with SD/BCW (1.0 mm) 1:16 compost was not significantly different from the yield of plants fertilized with RH/BCW (2.0 mm) 1:4 compost. These yields were not different from the yields of *Amaranthus cruentus* fertilized with RH/BCW (1.0 mm) 1:4 compost and RH/BCW (0.5 mm) 1:4 compost. These yields were significantly (P < 0.05) higher than the yields of *Amaranthus cruentus* fertilized with the remaining compost treatments. However, some of the yields in the remaining treated plants did not differ. The lowest yield was obtained in the control.

The fresh leaf yield of*Amaranthus cruentus*in 2017 season was significantly (P < 0.05) higher in plants grownon RH/BCW (0.5 mm) 1:1 compostthan in plants fertilized with SD/BCW (2.0 mm) 1:16 compost.These yieldswere significantly higher than the yieldsof*Amaranthus cruentus*fertilized with the remaining compost treatments. However, some of the yields in the remaining treated plants were not significantly different. The lowest yield was obtained in the control.

The results revealed that the fresh leaf yield of *Amaranthuscruentus*was significantly (P < 0.05) higher in plot fertilized with RH/BCW (1:1) 0.5mm compost (11.47 and 9.47 t/ha) in 2016and 2017 seasons, respectively than in other fertilized plots relative

TABLE 17

Fresh leaf yield (ton/ha) of *Amaranthuscruentus*in 2016 and 2017 cropping seasons

Treatment	Fresh leaf yield (t/ha) 2016	2017
RH/BCW 0.5 mm 1:1	11.47a	9.47a
RH/BCW 0.5 mm 1:4	9.71cd	6.60h
RH/BCW 0.5 mm 1:8	9.12ef	6.76h
RH/BCW 0.5 mm 1:16	8.64g	6.15j
RH/BCW 1.0 mm 1:1	9.24e	7.82f
RH/BCW 1.0 mm 1:4	9.79cd	7.21g
RH/BCW 1.0 mm 1:8	8.27h	6.18j
RH/BCW 1.0 mm 1:16	9.03f	7.12g
RH/BCW 2.0 mm 1:1	6.73l	5.00m
RH/BCW 2.0 mm 1:4	9.83c	9.03c
RH/BCW 2.0 mm 1:8	9.14ef	8.61d
RH/BCW 2.0 mm 1:16	8.17h	6.66h
SD/BCW 0.5 mm 1:1	7.61j	6.19j
SD/BCW 0.5 mm 1:4	6.15n	4.77n
SD/BCW 0.5 mm 1:8	5.96o	4.81n
SD/BCW 0.5 mm 1:16	8.72g	6.59i
SD/BCW 1.0 mm 1:1	8.22h	6.57i
SD/BCW 1.0 mm 1:4	7.84i	6.77h
SD/BCW 1.0 mm 1:8	7.02k	5.56k
SD/BCW 1.0 mm 1:16	9.83c	7.96f
SD/BCW 2.0 mm 1:1	9.66d	8.42e
SD/BCW 2.0 mm 1:4	6.01o	4.63o
SD/BCW 2.0 mm 1:8	6.38m	5.14l
SD/BCW 2.0 mm 1:16	10.43b	9.32b
Control	4.64p	3.49p

Means with the same superscript along the same column are not significantly different (p<0.05)

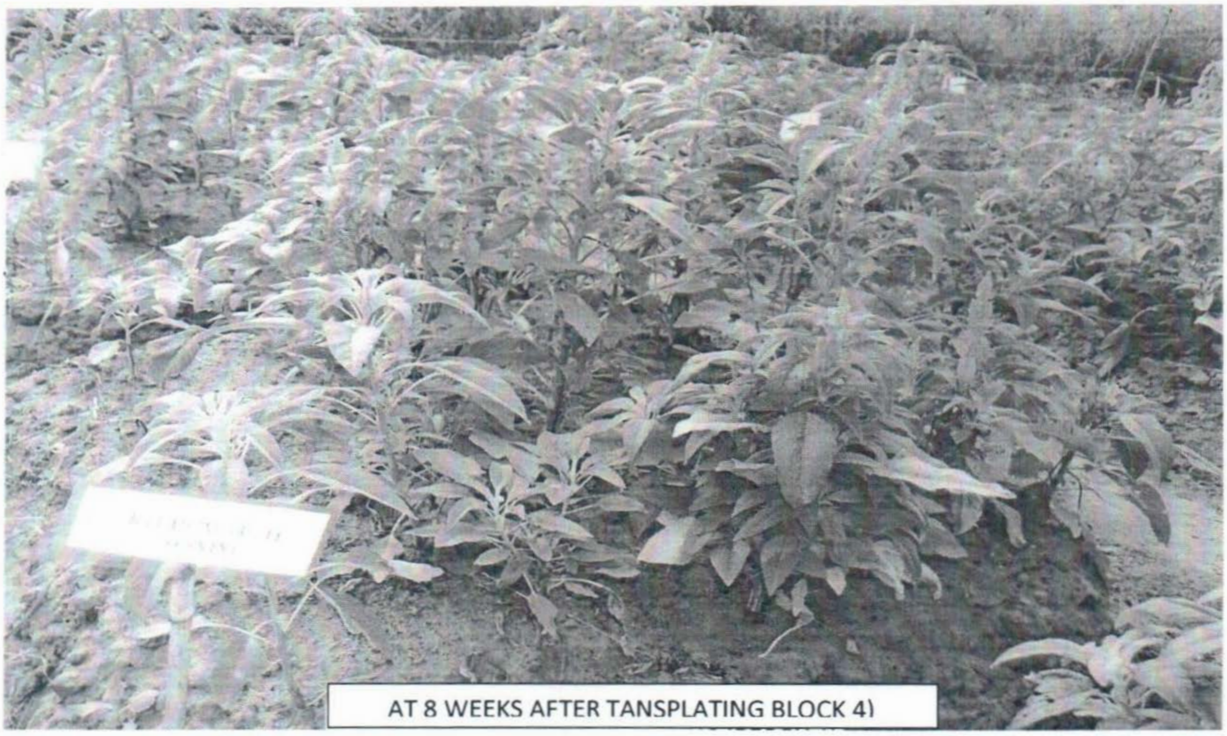


PLATE 7:*Amaranthus cruentus* with the highest fresh leaf yield treated with RH/BCW compost prepared in 1:1 composting ratio and 0.5 mm particle size

to the control. Comparatively, the fresh leaf yields of *Amaranthuscruentus*in 2016 season were higher than the yield valuesobtained in 2017 cropping season.The trend might be attributed to loss of available nutrients through leaching by rainfall in the 2017 season. The fresh leaf yield of *Amaranthuscruentus* was significantlyhigher in plots fertilized with RH/BCW composts than in plots fertilized with SD/BCW composts in 2016 and 2017 cropping seasons relative to control. The yield of *Amaranthuscruentus*in plots fertilized with RH/BCW composts ranged from 6.73 to 11.47 t/ha and 5.0 to 9.47 t/ha in 2016 and 2017 seasons, respectively. The yield of *Amaranthuscruentus*in plots fertilized with SD/BCW composts ranged from 5.96 to 10.43 t/ha and 4.63 to 9.32 t/ha in 2016 and 2017 seasons, respectively. The yield values of *Amaranthuscruentus* in unamended plots (control) were 4.64 and 3.49 t/ha in 2016 and 2017 seasons, respectively.The fresh leaf yields of *Amaranthus* grown on RH/BCW (0.5mm) 1:1 compost in 2016 and 2017 cropping seasons were significantly ($P < 0.05$) heavier than those produced on SD/BCW composts and the control. However, SD/BCW (2.0 mm) 1:16 compost produced significantly ($P < 0.05$) heavier fresh leaf yields in 2016 and 2017 seasons than other RH/BCW compost treatments. Therefore, SD/BCW (2.0 mm) 1:16 compost is ranked second in terms of yield performance. Fresh leaf yields of *Amaranthus* harvested from RH/BCW and SD/BCW composts were also significantly ($P < 0.05$) heavier than the ones grown on the native soil. Ogbodo (2012) observed that mixing rice husk and sawdust with

Therefore, organic manure (Eghareyba and Ogbe, 2002) has been found to sustain yield under continuous cropping and improve the fertility of a degraded soil.

Soil fertility management is a panacea for sustainable crop production in the degraded soils of the humid and sub-humid tropical regions. Soils of the south-eastern region of Nigeria are characterized by low inherent fertility, strongly weathered, acidic in reaction, fragile in nature, low in organic matter and other essential nutrient elements highly needed by plants (Ibia, 2005). The soils of Akwa Ibom State are rated low in the contents of major nutrients. These soils (Chude *et al.*, 2005) are poor in fertility culminating to low cation exchange capacity, base saturation and high concentration of exchangeable Al^{3+}, which dominates the soil exchange complex. Therefore, organic fertilizer (Agbede *et al.*, 2015) was reported to improve the availability of essential nutrients in deficient soils and its base elements content capable of reducing soil acidity.

Application of organic wastes to the soil has been identified as a good fertility management system for sustainable crop production. Organic resources contain more plant nutrients than the nitrogen, phosphorus and potassium commonly found in chemical fertilizers.In order to ensure sustainable crop production on these soils, there is need to produce composts with organic materials of different carbon/nitrogen ratios and particle sizes that would result in high quality compost and increase the yield of *Amaranthus cruentus*.

Now that chemical fertilizers are very expensive and scarce to acquire and the global attention is directed to the use of organically based fertilizers, it is ideal to produce organic fertilizers for the reach of peasant farmers as one of the problems encountered by amaranth growers is inadequate supply of inorganic fertilizers and lack of finance to buy the fertilizers (Olufolaji *et al*., 1990). It was opined by Akparobi (2009) that high quality amaranth can be made available at reduced price when organic manure is used.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Soil fertility management enhances and ensures sustainable agricultural production and guaranteeshealthy living. Supplying the soil with essential plant nutrients, creating conducive environment for soil organisms and conserving the soil for continuous use are important indices of soil fertility management. Farmers should be well informed about the modern technology of improving the fertility of the soils such as the use of composting process in converting organic materials to useful organic fertilizers capable of improving the low inherent fertility of tropical soils.

In view of the above, studies carried out at the Teaching and Research Farm of Akwa Ibom State University, Obio Akpa Campus revealed that:

I. The initial C/N ratio of organic materials is one of the most important factors influencing compost quality. The particle size of organic materials affect the time required for compost maturity and the quality of the cured compost.

II. The textural class of the post-planting soil remained as it was before the application of the various compost treatments. Application of various compost treatments increased the pH of thepost-planting soils to acidic and near neutral range. The EC, exchangeable bases, Cu, Zn and Mn increased with application of composts. The C/N ratio of the post-planting soil reduced with compost application while organic carbon, total nitrogen and iron contents were low in the post-planting soil.

III. The weights of composts reduced by 78 – 95 % at 4 WAC and 79 – 96 % at 8 WAC.

IV. Temperature rise wasobserved in SD/BCW (1:16) 2.0 mm compost (56.3°C) at 3 days of composting. Maximum temperature was obtained in SD/BCW (0.5 mm) 1:16 compost (60.8 °C) at 6 days of composting.

V. Eight species of bacteria, one species of actinomycetes and nine species of fungi were detected in the composts at 8 WAC.

VI. High content of N, P, K, Ca, Mg and Mn in *Amaranthus cruentus*were observed in plants treated with SD/BCW composts while Cu, Zn and Fe contents were high in plants treated with RH/BCW at 9 WAT in the two cropping seasons.

VII. The effects of C/N ratios of the three particle sizes of rice husk and sawdust in composting of poultry manure revealed that rice husk (RH) with initial C/N ratio of 10:1 to 16:1 combined with poultry manure with initial C/N ratio of 8:1 had the lowest C/N ratio at 8 WAC while sawdust with initial C/N ratio of 43:1 to 66:1 combined with poultry manure with C/N ratio of 8:1 had higher C/N ratio than RH/BCW composts. However, the C/N ratios of RH/BCW and SD/BCW composts at 8 WAC were within mineralization range capable of enhancing nutrients release and supporting sustainable *Amaranthus* production.

VIII. The highest plant heights were obtained in *Amaranthus* treated with RH/BCW (0.5 mm) 1:16 compost in 2016 season and in *Amaranthus* treated with RH/BCW (0.5 mm) 1:8 compost in 2017 season at 8 WAT. The widest stem girths were obtained in *Amaranthus* treated with SD/BCW (1.0 mm) 1:16 compost in 2016 season and in *Amaranthus* treated with RH/BCW (0.5 mm) 1:4 compost in 2017 season at 8 WAT. The broadest leaf areas were obtained in *Amaranthus* treated with SD/BCW (2.0 mm) 1:16 compost in 2016 and

2017 seasons at 8 WAT. The highest yields were obtained in *Amaranthus* treated with RH/BCW (0.5 mm) 1:1 compost in 2016 and 2017 seasons.

In conclusion, the carbon/nitrogen ratios and particle sizes of organic materials determine the rate of decomposition of the materials and the quality of the cured compost for sustainable *Amaranthus cruentus* production.

The following recommendations are made:

1. Fresh organic wastes should be recycledthrough composting process to produce quality compostfor soil fertility management instead of using raw organic waste.
2. Composting of organic wastes withdifferent C/N ratiosunder favourable condition should be practiced to ensureits rapid decompositionfor high quality composts that could support sustainable crop production.
3. Carbon source organic materials should be separated into distinct particle sizes for rapid decomposition and removal of impurities for quality control.
4. From the findings in the study, application of RH/BCW (1:1) 0.5 mmcompostfor soil fertility management and *Amaranthuscruentus*production in an acid soil of Obio Akpa, Akwa Ibom State, Nigeria is highly recommended.

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Appendix 1

Actinomycetes, Bacteria and Fungi Isolated from the Composts

S/N	SAMPLE CODE	Actinomycetes isolates	Bacteria isolates	Fungi isolates
1	SD/BCW (1:1) 0.5 mm		*Xanthomonas sp, Bacillus sp*	*Penicillium sp, Mould sp, Scopulariopsis sp*
2	SD/BCW (1:4) 0.5 mm	*Actinomyces sp,*	*Xanthomonas sp, Bacillus sp, Micrococcus sp*	*Penicillium sp, Mould sp, Yeast sp*
3	SD/BCW (1:8) 0.5 mm		*Bacillus sp*	*Mould sp, Trichoderma sp, Scopulariopsis sp*
4	SD/BCW (1:16) 0.5 mm		*Bacillus sp*	*Penicillium sp, Trichoderma sp, Aspergillus niger, Mould sp*
5	SD/BCW (1:1) 1.0 mm	*Actinomyces sp*	*Bacillus sp, Xanthomonas sp,*	*Mould sp, Yeast sp*
6	SD/BCW (1:4) 1.0 mm		*Xanthomonas sp, Bacillus sp*	*Aspergillus carbonacious, Mould sp, Aspergillus fumigatus*
7	SD/BCW (1:8) 1.0 mm		*Xanthomonas sp, Bacillus sp*	*Mould sp, Aspergillus carbonacious, Aspergillus fumigatus*
8	SD/BCW (1:16) 1.0 mm		*Bacillus sp, Staphylococcus aureus, Staphylococcus epidermidis, Pseudomonas sp*	*Penicillum sp, Aspergillus flavus, Mould sp*
9	SD/BCW (1:1) 2.0 mm		*Xanthomonas sp, Bacillus sp, Pseudomonas sp*	*Mould sp, Penicillium sp, Trichoderma sp*
10	SD/BCW (1:4) 2.0 mm	*Actinomyces sp,*	*Bacillus sp, Xanthomonas sp, Micrococcus sp*	*Penicillium sp, Trichoderma sp*
11	SD/BCW (1:8) 2.0 mm		*Bacillus sp, Xanthomonas sp, Staphylococcus aureus*	*Trichoderma sp, Aspergillus carbonacious, Penicillium sp,*
12	SD/BCW (1:16) 2.0 mm		*Xanthomonas sp, Bacillus sp, Staphylococcus aureus, Pseudomonas sp*	*Yeast sp, Penicillium sp, Aspergillus flavus, Aspergillus niger*
13	RH/BCW (1:1) 0.5 mm		*Bacillus sp, Xanthomonas sp*	*Mould sp, Penicillium sp, Trichoderma sp*
14	RH/BCW (1:4) 0.5 mm		*Bacillus sp, Staphylococcus aureus, Xanthomonas sp,*	*Aspergillus niger, Aspergillus flavus, Yeast sp, Trichoderma*

		Pseudomonas sp	*sp*
15	RH/BCW (1:8) 0.5 mm	*Bacillus sp*	*Yeast sp, Mould sp, Aspergillus carbonaceous*
16	RH/BCW (1:16) 0.5 mm	*Xanthomonas sp, Staphylococcus aureus, Staphylococcus epidermidis*	*Yeast sp, Mould sp, Aspergillus carbonaceous*
17	RH/BCW (1:1) 1.0 mm	*Xanthomonas sp, Bacillus sp, Staphylococcus aureus, Bacillus subtilis*	*Aspergillus carbonaceous, Aspergillus flavus, Yeast sp, Penicillium sp, Trichoderma sp*
18	RH/BCW (1:4) 1.0 mm	*Pseudomonas sp, Bacillus sp, Bacillus subtilis, Staphylococcus aureus*	*Mould sp, Penicillium sp*
19	RH/BCW (1:8) 1.0 mm	*Pseudomonas sp, Bacillus subtilis, Bacillus sp, Xanthomonas sp*	*Penicillium sp, Mould sp, Aspergillus flavus*
20	RH/BCW (1:16) 1.0 mm	*Bacillus sp, Staphylococcus aureus, Pseudomonas sp*	*Yeast sp, Penicillium sp, Mould sp*
21	RH/BCW (1:1) 2.0 mm	*Bacillus sp, Staphylococcus aureus, Serratia sp, Bacillus subtilis*	*Mould sp, Yeast sp, Aspergillus flavus*
22	RH/BCW (1:4) 2.0 mm	*Bacillus sp, Staphylococcus aureus, Bacillus subtilis, Micrococcus sp, Xanthomonas sp*	*Penicillium sp, Yeast sp, Mould sp*
23	RH/BCW (1:8) 2.0 mm	*Bacillus sp, Staphylococcus aureus*	*Mould sp, Trichoderma sp*
24	RH/BCW (1:16) 2.0 mm	*Bacillus sp*	*Mould sp, Trichoderma sp, Yeast sp*

Appendix 2

Percentage incidences of actinomycete, bacteria and fungi isolates in the composts

S/N	Bacteria	Incidence	Percentage incidence
1.	*Xanthomonas sp*	15	21.4
2.	*Bacillus sp*	23	32.9
3.	*Micrococcus sp*	3	4.3
4.	*Staphylococcus aureus*	11	15.7
5.	*Staphylococcus epidermidis*	2	2.9
6.	*Pseudomonas sp*	7	10.0
7.	*Bacillus subtilis*	5	7.1
8.	*Serratia sp*	1	1.4
	Fungi	Incidence	Percentage incidence
9.	*Penicillium sp*	15	20.3
10.	*Mould sp*	19	25.7
11.	*Scopulariopsis sp*	2	2.7
12.	*Yeast sp*	11	14.9
13.	*Trichoderma sp*	10	13.5
14.	*Aspergillus niger*	3	4.0
15.	*Aspergillus carbonaceous*	6	8.1
16.	*Aspergillus fumigatus*	2	2.7
17.	*Aspergillus flavus*	6	8.1
Actinomycetes		Incidence	Percentage incidence
18	*Actinomyces sp*	3	4.3