

**IMPROVEMENT OF SOIL QUALITY AND MAIZE  
(*Zea mays* L.) PERFORMANCE USING SELECTED  
WEED SPECIES AS SOIL AMENDMENT**

**BY**

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## CERTIFICATION PAGE

This certifies that this thesis has been read and approved as meeting the requirements of the department of Agronomy, University of Ilorin, Ilorin, Nigeria for the award of the P. h. D. degree in Soil Science.

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## **DEDICATION PAGE**

This research work is dedicated to my spiritual guidance Maolana Sheikh Ibrahim Inyas Kaolakh and Sheikh Nuruakeem

## DECLARATION PAGE

I, YUSUF Saidu Adewumi hereby declare that this thesis entitled “Improvement of soil quality and maize (*Zea mays* L.) performance using selected weed species as soil amendment” is a record of my research work. It has neither been presented nor accepted in any previous application for a higher degree. All sources of information have been specifically acknowledged.

In addition, the research work has been ethically approved by the University Ethical Review Committee.

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## ABSTRACT

Continuous cropping and poor soil management have resulted in reduced crop yield in southern Guinea savannah (SGS) zone of Nigeria. Effective soil management strategy to restore essential soil nutrients is thus required. This study assessed the potential of selected weed species as soil amendment for improved soil quality and crop performance in SGS. The specific objectives of the study were to: (i) assess the effect of soil amendments on the soil microbial population, succession and diversity; (ii) evaluate the effects of the combination of varying rates of the amendments on soil properties; (iii) evaluate the effect of the amendments on soil productivity using maize as test crop; and (iv) investigate relationships between soil quality indicators and maize yield components.

Weed species (*Amaranthus spinosus*, *Aspilia africana* and *Chromolaena odorata*) were screened for ability to improve soil quality and maize performance in a preliminary potted experiment using a complete randomized design (CRD). *C. odorata* was selected for the field experiment. A randomized complete block design (RCBD) was adopted for field experiments conducted in 2014 -2015 growing seasons with application of *C.odorata* at 10 t/ha and 15t/ha singly and in combination with NPK (60-30-15kg/ha) as well as sole application of NPK (120-60-30kg/ha) in maize plots. The plate culture technique was used for microbial analysis of soil dilutions. Data collected on soil and yield computed were subjected to analysis of variance. Pearson Product Moment correlation coefficient was used to establish relationships between the measured soil quality indicators and maize yield components.

The findings of the study were:

- (i) soil amendment with *C. odorata* increased soil microbial population (22.73 %) and diversity (11.11 %) within the first four weeks of application. Proliferation of saprophytes and suppression of pathogens were observed as decomposition *C. odorata* progressed;
- (ii) soil amendment with 7.5 % w/w *C. odorata* gave significantly ( $P \leq 0.05$ ) higher; mean soil moisture content (SMC), 60.97 g/kg, total porosity, 48.73 %, bulk density, 1.36 g/cm<sup>3</sup> and grain yield, (72.40 g/plant) than other treatments;
- (iii) *C.odorata* at 15t/ha combined with NPK fertilizer (60-30-15 kg/ha) on the field, increased soil organic matter (SOM) and ECEC by 80.91 % and 72.36 % respectively after second year harvest. This rate had significantly higher values of mean SMC (76.40 g/kg), total porosity (49.43 %), % water filled pore spaces (20.68 %) and lower bulk density (1.39 g/cm<sup>3</sup> to 1.34 g/cm<sup>3</sup>) at the end of second cropping season than other treatments;
- (iv) *C. odorata* at 15 t/ha combined with NPK (60-30-15 kg/ha) produced significantly higher mean maize cobs weight (11.46 kg/plot), mean grain yield (4.67 t/ha)
- (v) SOM was positively correlated with soil exchangeable bases, total N and available P with correlation coefficient (r) ranging from 0.65- 0.93. Most measured yield components were also strongly correlated with each other with r ranging from 0.13 to 0.99.

It was concluded that *C.odorata* has great potential for use as soil amendment in SGS zone to improve soil productivity. Application of 15 t/ha of *C. odorata* combined with NPK (60-30-15 kg/ha) was recommended for improved soil quality and maize performance in the region.

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## **CHAPTER ONE**

### **1.0 INTRODUCTION**

The declining soil fertility and productivity resulting from shortened fallow periods and continuous cultivation, with little or no inputs, has been cited as the most significant constraint threatening food production by small scale farms in sub-Saharan Africa (Asfaw, 2007; Adamu, 2015). Most soils in Southern Guinea Savannah zone is known for their low clay and organic matter contents, leaching by intense rainfall, high weatherability of the soils as well as presence of kaolinitic clay as the dominant mineral (Enwezor *et al.*, 1989; Odunze and Kureh, 2009). Thus, appropriate soil fertility management remains the key factor for increasing crop production in this agro-ecological zone.

At present, many small smallholder farms in this zone, employ different strategies to minimize the negative effects of low soil fertility such as using low plant population density, applying mineral fertilizer or green manure as well as adoption of fallow period (Badu-Apraku *et al.*, 2005). However, as a result of increasing population pressure and other competing alternative uses for land, the traditional fallow period has been reduced drastically in this agro-ecological zone (Asadu and Unagwu, 2012; Nafiu *et al.*, 2012).

Use of livestock manure or plant materials had received worldwide support for soil quality and productivity improvement of degraded and nutrient poor soils (Tejada and Benitez, 2014). Since the development of modern agriculture, green manure has been

used as soil amendment material on the farm to improve or restore its desirable quality (Omotayo and Chukwuka, 2009). However, biophysical characterization of Nigeria farming systems has revealed that organic resources accessible to farmers are highly heterogeneous. Most of these organic resources utilized on farm are low or, generally, of intermediate quality since they are often used in mixture (Fening *et al.*, 2009; Omotayo and Chukwuka, 2009).

In Nigeria, chemical fertilizers are generally used to supplement the inherent potential of the soil to supply the necessary nutrients for the crops and are therefore, of great importance. However, empirical studies had revealed that chemical fertilizers have the potential to disturb the equilibrium of agro-ecosystem and pollute the environment. This includes the pollution of ground water system and surface water due to run off which contains nitrates. This results in acidified soils, and consequently reduced microbial activities and soil micronutrients deficiency (David *et al.*, 2012). There is therefore, the need for gradual transformation from chemical-based farming system to a more sustainable agricultural practice that will improve soil quality and productivity at relatively low cost.

Soil amendment is organic material added to soil to enhance plant growth directly and indirectly through improvement in soil nutrient supply, soil physical condition (soil structure, tilth, water infiltration, water holding capacity) and microbial population (Malihe *et al.*, 2014; Grey, 2016; Cercioglu, 2017; Page-Dumroese *et al.*, 2018). Organic amendments are non pollutant, renewable- resources that improves physical, chemical and biological properties of the soil at a reduced cost for resource- poor rural farmers. It is also posited that organic amendment promotes naturally, the proliferation of beneficial soil microorganisms when incorporated into the soil (Higa and Parr,

1994; Jacqueline *et al.*, 2012). It is, therefore, likely that soil amendment provides other benefits such as improved plant health due to reduction of pathogens since plant health is affirmed to be intimately linked to soil health (Akhtar and Malik and Malik and Malik, 2000). Furthermore, managing the soil in ways that conserve and enhance the soil biota can improve crop yield and quality, now that soil quality and soil health have been receiving necessary attention in recent time (Arshad and Martin, 2002).

*Aspilia africana*, *Amaranthus spinosus* and *Chromolaena odorata* (common weed plants) contain balanced supply of essential nutrients particularly N, P, K, Mg, Ca, Zn and other micronutrients (Adeniyi and Odofowora, 2000; Okwu and Josiah, 2006; Igboh *et al.*, 2009; Abii and Onuoha, 2011; Amiolemen, *et al.*, 2012). These three plants are among plant materials generally used in traditional medicine probably because of their antimicrobial properties. These antimicrobial properties are attributed to the presence of chemical compounds like flavonoids, saponins, tannins, steroids, etc, in their leaf extracts (Okoli *et al.*, 2007; Vital and Rivera, 2009; Therbo *et al.*, 2010; and Kasim *et al.*, 2012)

*Aspilia africana* is reported to possess chemical compounds that can inhibit clinical isolates; bacteria like *Klebsiella pneumonia* and *Staphylococcus aureus* and *Escherichia coli* (Anibijuwon *et al.*, 2010). *Amaranthus spinosus* is also reported to show inhibiting activity against some pathogenic organisms such as *Fusarium* spp. *Salmonella typhi* and *Escherichia coli* (Kasim *et al.*, 2012). *Chromolaena odorata* was observed to be capable of inhibiting the growth of *Salmonella typhimurium*, *Staphylococcus aureus* and *Escherichia coli* (Vital and Rivera, 2009; Anyasor *et al.*, 2011). In other words, if used as organic amendment, these plants, may apart from

supplying plant nutrients through mineralization, also inhibit or suppress some soil-borne microbial plant pathogens.

All these therefore provide basis for investigating the resource qualities and possible use of these three weeds (*Amaranthus*, *Aspilia* and *Chromolaena*) as organic amendments for soil quality improvement.

### **1.1 Statement of the Problem**

Soil in Guinea Savannah zone of Nigeria is characterized by low or no activity clay and low Soil Organic Matter content resulting in poor water and nutrients holding capacity (Juo *et al.*, 1995; Odunze and Kureh, 2009). There is therefore the need to develop soil management system that will improve soil structural aggregation, reduce nutrient lost through erosion and leaching via constant supply of organic material for agricultural sustainability in this zone.

Increasing population pressure and other competing alternative uses of land also make the required traditional fallow period impracticable thereby leading to continuous decline in soil quality and productivity (Asadu and Unagwu, 2012)

The traditional farming practice that involves annual land clearing and tilling destroys soil structure and Soil Organic Matter. Hence, the need for farming systems that will employ combinations of fertility building practices appropriate to the local condition for crop production in this agro- ecological zone

Intensive cultivation of land without application of inorganic fertilizer and organic amendments in Guinea Savannah zone of Nigeria is not sustainable (Eche *et al.*, 2014). However application of chemical fertilizer alone has the capacity to disturb the

equilibrium of agro-ecosystem, adversely affects soil and plant health, pollutes the environment, threatening the country food security as well as economic power of the farmers (David *et al.*, 2012).

Mineral fertilizer and other chemical inputs have been reported to affect soil biodiversity negatively with reduction in population of some beneficial soil microbes. There is therefore the need to improve soil biodiversity via organic amendments application so as to increase naturally beneficial soil microorganisms' population since sustainability of agricultural productivity is posited to be a function of soil biophysical and chemical properties (Ezeaku, 2013).

## **1.2 Justification for the study**

Nigerian Population is said to be increasing at the rate of 2.67% per annum while farm productivity is on the decline (Nagy and Edun, 2002): In January 2017, the population of Nigeria was estimated to be 189, 559, 502 people and predicted to reach 194, 615, 054 in the beginning of 2018 (United Nation's Department of Economic and Social Affairs: Population Division's 2017 report). This implies that there will be a continuous shortfall between food demand and supply unless soil productivity is increased through soil quality improvement.

The increase in importation of food items as a result of increase in the demand for food than the local supply: The office of Agricultural Affairs, United States consulate in 2017 reported an estimate of Nigeria's food and agricultural imports of more than ten billion dollars (\$10,000,000) in 2015 alone. This may have a far reaching implication in agricultural development in the country

Yield decline reported annually is attributed to shortened fallow periods, insufficient plant nutrients, low Soil Organic Matter content as a result of intensive cropping system, poor soil management practices and low active clay content resulting in low Cation Exchange Capacity (CEC) and erratic climatic change in Southern Guinea Savannah ecological zone of Nigeria (Nagy and Edun, 2002).

The cost of mineral fertilizers is high as a result of subsidy removal policy. This makes it too expensive for the resources-poor small scale farmers in Nigeria. In most cases quantities of fertilizer lower than the recommended rate are applied by many small scale farmers and this usually leads to reduction in crop yield and profit (Onasanya *et al.*, 2009).

Mineral fertilizers are usually not available at the time of need. This is usually due to poor distribution system. Too many middle men were reported to be involved before the commodity finally gets to the farmers.

There is a need to regulate the quantity of chemical inputs used by farmers in the soil for environmental sustainability and there is general advocacy for organic food.

The need to assess the possibility of organic amendments for improving the suppressiveness of the soil after incorporation into the soil thereby enhancing soil health bearing in mind that it is only healthy soil that can produce healthy crops (FAO, 2015).

There is therefore the need to identify and possibly convert some common weed(s) species found in the farm vicinity to organic resource. This can be achieved via a well coordinated soil amendment technology that reduces external inputs and maximizes the internal inputs already existing on the farm, thereby reducing the cost and amount

of mineral fertilizer required by farmers for soil fertility and productivity improvement.

### **1.3 Main Objective of the Study**

The main objective of this study was to assess the potential of common weeds *Amaranthus spinosus*, *Aspilia africana* and *Chromolaena odorata* as soil amendment materials, with a view to improve soil productivity while sustaining the environment by reduction in chemical input use in Southern Guinea Savannah zone of Nigeria.

#### **Specific objectives of the study**

The specific objectives of the study were to:

- (i) evaluate the effects of the combination of varying rates of the amendment materials on soil properties;
- (ii) assess the effect of the amendments on the soil microbial population, succession and diversity;
- (iii) evaluate the effect of the soil amendments on soil productivity using maize as test crop; and
- (iv) investigate relationships between soil quality indicators and maize yield components

## **CHAPTER TWO**

### **2.0 REVIEW OF LITERATURE**

#### **2.1.1 Soil quality and food security**

Soil is a natural resource for agricultural production, for food security and maintenance of most life processes (Bello and Olaoye, 2009). In many, areas of the world, soil fertility is declining and erosion degradation is getting worse. Worldwide, an estimated two billion hectares of land are considered less productive as one of the consequences of land degradation; due to deterioration of essential soil processes (Abiala *et al.*, 2013). The deterioration usually results from organic matter depletion and loss of beneficial soil flora and fauna, nutrient depletion as a result of continuous cropping and soil erosion, crusting and sealing, acidification and pollution (Akinbode, 2010).

Loss of soil structure and fertility, together with the increasing incidence of pests, weeds and diseases, are consequences of small-scale farmers practices such as shifting or semi shifting cultivation, and intensive cultivation (Yusuf, 2010)). Poor soil management practices have resulted in reduced crop yield in Southern Guinea Savannah zone of Nigeria (Ojeniyi *et al.*, 2012). Intensive soil tillage practices accelerates soil erosion, causes surface compaction of soil and loss of organic matter (Longinus and Benjamin, 2014)). These mostly resulted to decline in soil productivity.

The major soils found in the various savannah zones of Nigeria have coarse-textured surface and are low in organic matter and chemical fertility (Abiala *et al.*, 2013; Eche *et al.*, 2014). Land clearing for continuous cropping exposes the soil for damaging climatic influences. This lowers soil fertility and thus poses many constraints on intensive food crop production in Nigeria (Longinus and Benjamin, 2014). Yield decline reported annually is attributed to insufficient plant nutrients, loss of Soil Organic Matter content as a result of intensive cropping system, poor soil management practices as well as erratic climatic change in the Southern Guinea Savannah ecological zone of Nigeria (Nagg, 2002).

### **2. 1.2 Soil Health and Soil Productivity**

The concept of soil health and soil quality have received considerable attention in recent because of their fundamental role in the preservation of ecological functions for future generations (Ashard and Martin, 2002; Karlen *et al.*, 2003; Kibblewhite *et al.*, 2008). Soil health and soil quality are terms commonly used interchangeably to describe soils that are fertile and also possess adequate physical and biological properties to sustain crop productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). Soil quality is most simply defined as the capacity of the soil to function (Michael *et al.*, 2015). It is how well soil does what we want it to do while soil health is the continued capacity of soil to function as a vital living system, by recognizing that it consists of biological elements that are important to ecosystem function within land-use boundaries (Doran and Zeiss, 2000; Karlen *et al.*, 2001).

Karlen *et al.* (1997) defines soil quality as the capacity of soil to function to sustain plant and animal productivities, to maintain or enhance water and air quality and to support human health and habitation. Therefore, important soil functions for crop production include: promote hydroconductivity and retention, solute transport and retention, structural stability and support; retention and cycling of nutrients; buffering and filtering of potentially toxic materials; and maintenance of biodiversity and habitat as well as promote plant, human and animal health (Doran and Parkin., 1996; Michael *et al.*, 2015).

Tianna (2012) and Michael *et al.* (2015) stated that soil health is the foundation of productive and sustainable farming practices and that healthy and high quality soil is expected to have the following characteristics. Therefore, important soil functions for crop production include: promote hydroconductivity and retention, solute transport and retention, structural stability and support; retention and cycling of nutrients; buffering and filtering of potentially toxic materials; and maintenance of biodiversity.

### **2.1.3 Soil Organic Matter (SOM): an important soil quality indicator**

Marriott and Wander (2006) observed that the single most important soil quality indicator for nearly all soils throughout the world is SOM. It is also one of the most common deficiencies identified in degraded soils because of the numerous chemical, physical, and biological properties and processes it influences (Singer *et al.*, 2004). Soil Organic Matter is generally measured based on the concentration of Soil Organic Carbon (SOC), because about 58% of the SOM is accounted for by SOC (Tu *et al.*, 2006).

James and Rafiq (2010) stated that SOM is basically all the organic substances (anything with carbon) in the soils, both living and dead. SOM consists of different components; the living (microorganisms), the dead (fresh residues) and very dead (Humus) fraction which is long term SOM fraction that is thousands of years old and is resistance to decomposition. Soil Organic Matter is also grouped into active components (35%) – living and dead, fresh plant and/or animal materials which is food for microbes and is composed of easily digested sugars and proteins. The passive components (65%) are those resistance to decomposition by microbes and higher in lignin content. SOC value of less than 1.0% or 10 g/kg will indicate problems of low nutrient holding capacity. Organic preferred level is about 2% or 20 g/kg (Olabode *et al.*, 2007).

Increase in SOM, particularly in biologically-available forms, are intimately linked to changes in the size, activity and composition of the soil flora and fauna in the soil community (Teasdale, 2007; and Michael *et al.*, 2015). Effective SOM management involves balancing two ecological processes: mineralization of carbon (C) and nitrogen (N) in SOM for short-term crop uptake, and sequestering C and N in SOM pools for long-term maintenance of soil quality, including structure and fertility.

The mineralized or decomposed organic matter serves two (2) functions for micro organisms; providing energy for growth and supplying carbon for the formation of new cells (Elfstrand and Bath, 2007). Soils with more microbial activities have higher amounts of active carbon recycle and release more nutrients for plant growth than soils with less microbial activities and contain less active organic matter (Lamparter *et al.*, 2009; James and Rafiq, 2010). They reported that 100gs of SOM can yield about 60 – 80g of carbon dioxide leaving 20 – 40g of energy and nutrients to decomposed and

turned to 3 – 8g of micro organism (the living), 3 – 8g of non-humic compounds (the dead) and 10 – 30g of humus (the very dead matter, resistance to decomposition). Soil Organic Matter is by products of the C and N cycle; SOM = C, O<sub>2</sub>, H, N<sub>2</sub>, P and S.

Soil Organic Matter is consumed and destroyed by soil microbes. Although SOM is a storehouse for many plants nutrients, its level is slow to build in coarse textured soil, as a result of low storage capacity for nutrients (Gardner *et al.*, 2001; Elfstrand and Bath, 2007; Pikul *et al.*, 2008). In this case excess nutrients released are often leached to surface waters. When SOM is reduced, future storage of nutrients is also reduced. The indicators associated to SOM can be correlated with different chemical, physical and biological properties (major determinant of soil quality). Some of them having high sensitivity and their changes can offer useful information and make decision timely for a given agro-eco system (Martinez-Salgado *et al.*, 2010).

Some research authors reported that total organic carbon and total nitrogen were the most soil powerful attribute in discriminating among different management practices and therefore agreed that a 15% increase or decrease of SOM over a base line level seems reasonable (Hussain *et al.*, 1999; Arshad and Martins, 2002; Andrews *et al.*, 2004; John, 2007; Brian, 2014). It therefore means that an increase of 15% would indicate that adopted management practice had a significant effect on Soil Organic Matter content and conversely, a 15% decrease in organic matter would indicate corrective action should be taken to reverse the trend. It was noted that soil texture, soil pH and soil phosphorus did not vary significantly with land use and therefore not useful indicators in monitoring changes in soil quality under different soil management practices or conservation programmes.

Soil Organic Matter drives physical characteristics of soil-like structures and aggregation allow water and air to infiltrate, roots to explore, and biota to thrive. Diverse and active biological communities help soil resist physical degradation and cycle nutrients at rates to meet plant needs. (Weil and Magdoff, 2004; Kowaljow, 2007). Soil organic matter is the principal determinant of soil quality as far as crop production is concerned. It is a major source of plant macronutrients such as nitrogen, phosphorus and sulphur. It also stabilizes some important soil physical properties such as soil structure, bulk density, porosity, water filled pore spaces and so on (Erika and Erick, 2006).

Building up and maintenance of SOM is critical to soil productivity and generally corresponds to nutrient build up. Soil Organic Matter increases the CEC of the surface soil, this is especially important in Kaolinitic soil. Increasing SOM reduces P fixation in soil with high Fe and Al oxide contents.

Agboola (1994) reported that in West Africa Alfisols, Soil Organic Matter accounts for 80% of CEC as well as Ca, Mg, K and available P. Soil Organic Matter levels are also said to be highly correlated with CEC. The big opportunity for management in this type of soil is that SOM is a renewable resource whose level can be replenished by addition of organic input.

#### **2.1.4 Decomposition of organic materials in soil**

The decomposition of crop residues or green manures in the soil is a complex process, which is the result of the interaction between different factors (biotic and abiotic) specific of each environment (Wenjing *et al.*, 2013). However, the main abiotic factors that drive this process are related to their influence on soil organisms, since the

decomposition is essentially a biological process (Lavelle *et al.*, 1993; Poirier *et al.*, (2013). Physical fragmentation of organic residues provides an increase in surface area, facilitating microbial colonization and subsequent hydrolysis by microbial extracellular enzymes. Thus, complex polymers are degraded into monomeric compounds and ions, which can be absorbed by microbial cells or plants.

Lamparter *et al.* (2009) reported that the factors that can affect the direction and magnitude of the decomposition process are the nutrient content and biochemical composition of the green manure or organic amendment added to the soil, the nature and abundance of the inhabitant microbial communities, soil moisture, temperature, aeration, pH, the carbon/nutrient ratios of SOM and the presence or absence of inhibitor substances.

In general, the compounds present in the plant cell cytoplasm and walls according to Horvath *et al.*, (2002) are waxes and pigments (1%), amino acids, nucleotides and sugars (5%), starch (2–20%), proteins (5–7%), hemicellulose (15–20%) cellulose (4–50%), lignin (8–20%) and secondary compounds (2–30%). He reported that most of these components are present in the primary and secondary cell walls of plant cells. The primary wall is formed basically by cellulose and hemicellulosesd that, as the primary wall growth ceases, the secondary walls begin to form, which has lignin as the main component and gives resistance to the cell wall.

Along with driving decomposition processes, fungi and bacteria are key intermediaries in energy flow in stream ecosystems. They break down large molecules, such as cellulose, chitin, and lignin, into smaller compounds that can be taken up by the organisms of higher trophic levels (Webster and Meyer (1997; Buesing and Gessner,

2006). Fungi are generally more efficient than bacteria in exploiting available organic resources through invasion and enzymatic hydrolysis of leaf material and lysed hyphae (Gulis and Suberkropp, 2003). Different groups of bacteria and fungi have various biochemical and physiological capabilities, and these differences may impact the leaf decomposition process that underscores the need to examine microbial community structure.

Zhu and Miller (2003) opined that it is the size and activity of soil microbial enzyme that regulates carbon accumulation via decomposition or mineralization of organic residues. They observed that the activities of soil invertase, and alkaline phosphatase were all greatly increased upon application of organic amendment. Both the biomass and diversity of soil microbes were also increased as a result of organic input (organic amendment). This response could be attributed to the fact that most soil microorganisms are heterotrophic.

Heterotrophic community is determined by quantity and quality of incorporated organic matter. Proliferation of any heterotrophic microorganism in microflora community depends on its ability to cope with competition of other organisms having similar enzymatic potential and the harm done by predators and parasites (Epstein, 1997; Gerard, 2016). When succulent plant tissues are incorporated into the soil, the abundance of bacteria around and within the buried materials increased rapidly initially, but decline by 7th day (Alexander, 1977; Madigan and Martinko, 2005).

According to Alexander (1977), species of *Pseudomonas*, *Mycobacterium*, *Micrococcus*, *Bacillus*, *Flavobacterium*, *Penicillium*, *Sclerotium*, *Fusarium* and *Aspergillus* are the most soil microbes that are active in the solubilization process of

organic and inorganic phosphorus. *Aspergillus*, some *Penicillium* and *Pseudomonas* species produce acids and chelating agents that play a part in the solubilization of soil and fertilizer phosphate (Konrad and Ernest, 1979; Andersen *et al.*, 2011; Klockgether, *et al.*, 2011)

Paul and Clark (1996) and Gerard (2016) also reported that the most frequently isolated species of bacteria responsible for solubilization of soil Phosphorus are *Pseudomonas* and *Bacillus*. Banik and Dey (1982) discovered that two *Aspergillus* species, two *Bacillus* strains and one actinomycete were efficient in solubilizing phosphates of Ca, Al and Fe. It was also revealed that some organisms cleave only the penta-or tetra-, but not hexaphosphate, and that the enzymes that are formed also differ, while some species make intercellular phytase, others excrete an extracellular catalyst. Moreover, though some phytases are reasonably specific and act chiefly or solely on inositol phosphate, others are really non specific phosphates removing P from the dissimilar organic compounds (Alexander, 1977; Markus and Joachim-Volker, 2013). Phytase activity according to Tinker (1980) is wide spread and that species of *Aspergillus*, *Penicillium*, *Rhizopus*, *Arthrobacter*, *Streptomyces*, *Pseudomonas* and *Bacillus* can synthesize the enzyme Phytase that solubilises phosphorus containing compounds in the soil.

#### **2.1.5 Amendment of soils for improved quality and crop production**

Over the years inorganic fertilizers have been widely used worldwide to support and optimize the growth and yield of crops (Mohammed *et al.*, 2016). Most Maize farmers in Guinea Savannah zone of Nigeria use inorganic fertilizers for better production due to its easy and rapid availability to plants. However, the use of mineral fertilizers on arable soils leads to serious negative impact on soil physical conditions, increase soil

acidity, promotes nutrients leaching and degrade SOM (David *et al.*, 2012). Albiach *et al.* (2000) posited that the continuous use of synthetic fertilizers can eventually damage the soil chemical, physical and biological properties.

Organic manure, on the other hand, provides beneficial effects to the soil and also increase availability of nutrients, which helps to improve the quality and yield of crops and are generally less expensive than inorganic fertilizers (Thy and Buntha, 2005). Organic fertilizers are not only the source of organic matter and plant nutrients, but also boost microbial population and diversity as well as physical and chemical properties of the soil (Albiach *et al.*, 2000).

Organic manures have been used as a means to increase soil quality and crop production all along the history of farming (George, 2002; Cercioglu, 2017). Organic residues were the only means of improving soil fertility until the development of synthetic chemical fertilizer (Asadu and Unagwu, 2012)

Organic inputs have been shown to help preserve natural resources and reduce degradation of ecosystem (Mader *et al.*, 2002; Francis and Daniel, 2004). As a result organic agriculture has become a useful substitute which promotes the use of natural organic compounds such as plant residues, manure, mulch and compost (Shannon *et al.*, 2002). Application of these natural organic compounds improves the soil nutritional state and as well as influencing other soil properties, such as CEC, soil aeration, water holding capacity and particles aggregation (Pagliai *et al.*, 2004) all of which contribute to better crop production, even with the use of little or no mineral fertilizer application.

Jerome *et al.* (2013) reported that legumes- based technologies for soil fertility management in small-scale farming systems in most sub-Sahara African countries were relatively unsuccessful in the past, as recommended legume species were mostly exotic and costs related to their management were unaffordable to some farmers.

Research report by Roget (2006) indicated that green manuring that involves incorporation of legume crops could induce increase in pathogenic microbial population as a result of accumulation of mineralized N in excess of crop requirement thereby disrupting natural soil microbial diversity. He explained that any factor that results in the accumulation of high available N level for long period will tend to curb the effectiveness of the future suppressiveness activity of the soil and the example of the factors cited were legume's pasture and crop left unharvested. He concluded that minimizing the accumulation of soil N will enables a more diverse and large soil microbial population to develop thereby enhancing soil health.

#### **2.1.6 Resource quality of *Chromolaena odorata* as amendment material**

Application of organic material as fertilizer provides growth regulating substances and improves the physical, chemical and biological properties of the soil (Belay *et al.*, 2001). However, the suitability of plant materials for soil amendments depends on its nutrients being above the level at which net N and P mobilization generally occur and relative rate of decomposition.

*Chromolaena odorata* has aroused the research interest in recent times because of the relatively high nutrients concentration found in its biomass. The abundance and the adaptability of it to various environments, ease of establishment, large biomass production, rapid growth rate, fast decomposition rate and low C/N ratio make it a

good material for soil resuscitation (Olabode *et al.*, 2007; Koutika and Rainey, 2010)). However the use of *C. odorata* is somewhat controversial, some researchers considered *C. odorata* as a weed (Olaoye, 1986; Waterhouse, 1994; MacFadyen and Skarratt, 1996). Others regarded it as beneficial fallow plant (Norgrove *et al.*, 2000; Ekeleme *et al.*, 2004; Koutika *et al.*, 2005).

Koutika and Rainey (2010) stated that *C. odorata* could be considered as a fallow plant based on the fact that it has ability to be nutrient sink, its potential benefits to the crop as regular source of organic matter and nutrients supply after slashing, its beneficial effects on exchangeable K concentration, its potential to be used as green manure as well as its better adaptability as fallow plant on acidic soil than some legumes. Similarly, Koutika *et al.* (2002) argued that *C. odorata* performed better than *Pueraria* legumes fallow in acidic soils of Southern Cameroon. He therefore challenged the weed management researchers to find a balance between the competitive role of *C. odorata* as a nutrient sink and its potential benefits to the crop as a regular source of organic matter.

Incorporation of *Chromolaena odorata* into the soil as organic amendment, as a way of recycling organic materials, can be described as turning a “waste product” into valuable soil resources. According to Norgrove (2007) previous studies in the tropical environment showed that *Chromolaena odorata* has a fast decomposition rate and might improve SOM quantity and quality. Kanmegne *et al.* (1999) reported that *C. odorata* decomposed fast with only 36% of its original weight remaining after 14 weeks. Also, Ibewero *et al.* (2000) and Tian *et al.* (2000) observed, in their independent research reports, that after 120 days of decomposition *Chromolaena* leaf residues has released nearly 75% as much as its initial pools of N and P. Trends of

time dynamic of soil organic carbon released and plant available N of *C. odorata* monitored by Ogundare *et al.* (2014) shows that the peak values were obtained at 30 and 60 days after incorporation into the soil.

Similarly, Julia *et al.* (2006) observed that 20% of *C. odorata* plant leave residues were decomposed after 3 weeks of incubation. They reported that after 60 days only 40% of the initial *Chromolaena* leaves remained and at the end of the decomposition study (after 120 days) only about 24% of initial *C. odorata* leaf plant residues remained. Also Chandrasehekara and Swamy (2010) reported only 20% of initial weight of *Chromolaena* mulch remain after 180 days. Various research reports stated that mass loss from decomposition residue is regulated by plant residue quality, the plant part used and their maturity stage (Palm and Sanchez, 1991; Palm *et al.*, 2001; Allison and Vitousek, 2004)

In the experiment conducted by Koutika *et al.* (2004), it was reported that  $\text{NH}_4^+$  -N mineralization was higher in *C. odorata* fallow than in legumes fallow. This suggests suppressive quality of soil with *C. odorata*'s organic matter because high  $\text{NH}_4^+$  -N level in soil are reported to be associated with reduction in take- all disease whist increasing  $\text{NO}_3^-$ -N levels result in increase expression of take all disease (Lehman *et al.*, 2015).

Babadele and Ogeniyi (2012) affirmed that *Chromolaena odorata* mulch was effective source of N, P, K, Ca and Mg and organic matter and increase yield of cassava. Taiwo and Lawrence (2014) reported that *C. odorata* biomass increased soil moisture content, total porosity, SOM content, soil nutrients level, reduced soil bulk density and subsequently produced high growth and yield of okra in forest- savannah transition zone of southwest of Nigeria.

### 2.1.7 Profile of the selected weeds used as amendment material

**Botanical Name :** *Amaranthus spinosus* (L)

**Common names:** Spiny amaranth

**Family:** Amaranthaceae.

**Habitat:** Refuse dumped area, cultivated beds, road sides etc. The plant can thrive well in moist light (sand), medium (loam) and heavy (clay) soils provided they are well drained. It can also grow in acid, neutral and alkaline soils. When grown in nitrogen rich soil, it is known to concentrate nitrate in the leaves (Ken and Hedrick, 2013).

**Description:** *Amaranthus spinosus* is a annual herb growing to a height of 0.6m, with sharp spins at the nodes.

**Reproduction and dispersal:** It is in leaf by April and flower from July to September. Its seeds ripen from August to October. The individual flowers are either male or female, but both sexes are located on the same plant (monoecious). *Amaranthus spinosus* is protergated by seeds, which are easily blown and spread by wind. Seeds may also be dispersed by farm machinery, water, vehicles, animals as well as in contaminated agricultural produce (Maiyo *et al.*, 2010).

**Antimicrobial properties:** Spiny amaranth is reported to contain various pharmacological active compounds. The leaves extract was said to demonstrate antimicrobial activity that was plant specific. It was said to possess ethno-pharmacological properties. (Maiyo *et al.*, 2010; Ken and Hedrick, 2013)

**Botanical Name :***Aspilia africana* (PERS) Adams

**Family:** Compositae.

**Habitat:** Field crops, fallow land particularly in the Forest zone of Nigeria. The plant can grow well in moist loam and clay soils provided they are well drained (Akobundu 1987).

**Description:** *Aspilia* is a perennial shrub widely grown in varying height from 60cm to 1.5m depending on rainfall. It is a common weed of field crops in West Africa Nigeria inclusive. The plant has glossy leaves with floret yellow flowers (Okoli *et al.*, 2007).

**Reproduction and dispersal:** It is in leaf by April and flower from July to September. Seeds matured from August to October. The plant propagated by seeds, which can be easily blown and dispersed by wind. Seeds may also be spread by farm machinery or other equipment, water, animals as well as in contaminated agricultural produce (Akobundu 1987; Okoli *et al.*, 2007). **Antimicrobial properties:** *Aspilia* plant leaves are being used in traditional medicine because of their therapeutic properties. For instance non-volatile leaf extracts of the plant are known to possess antimicrobial and anti-inflammatory activities (adeniyi and Odufowora 2000; Okoli *et al.*, 2007). Its efficacy in the treatment of wounds has also been reported (Okoli *et al.*, 2007)

**Botanical Name:** *Chromolaena odorata* (L.) KING and ROBINSON

**Common names:** Chromolaena, Siam weed, Armstrong's weed, butterfly weed, eupatorium, Jack-in-the-bush, king weed, paraffin bush, paraffin weed, turpentine

weed, traffic weed, Pelvic weed etc. It is called ‘Akintola’ or ‘Awolowo’ by Yoruba people of Nigeria (Onwugbuta, 2001: Anyasi, 2012).

**Family:** Asteraceae (Compositae).

**Habitat:** A potential weed of tropical and subtropical regions that invades banks of water courses, bush land, fallow land, forest margins, roadsides, disturbed sites, waste areas, neglected pastures, crops and plantations (Anyasi, 2012).

**Description:** An upright (erect) or sprawling shrub forming thickets growing an average of between 1.5 to 3 m tall in the field. When climbing over trees however *C. odorata* may reach greater heights 6-20 m. The succulent stems are generally yellowish-green and somewhat hairy (pubescent), but become woody towards the base of the plant. Several stems are usually produced from the plants long-lived root-stock (crown). They are multiple-branched, with the side (lateral) branches usually being produced in pairs in the leaf forks (axils). *C. odorata*- dominated fallow is sometimes used as an indicator for soft and more fertile soil (Onwugbuta, 2001: Nisit *et al.*, 2005).

**Reproduction and dispersal:** This plant flowers October to December, mainly reproduces by seeds, which are easily blown and dispersed by wind. Seeds may also be spread by machinery, water, vehicles, animals, in clothing, and in contaminated agricultural produce. Pieces of the crown of the plant can also take root and grow, and these may be spread about during cultivation and other soil moving activities (e.g. road maintenance).

### **2.1.8 Chemical composition and properties of *Chromolaena odorata***

Screening of *Chromolaena* revealed that essential oils of the leaf exhibit antibacterial and antifungal activity (Inya-Aga, *et al.*, 1987; Nisit *et al.*, 2005; Nanadini *et al.*, 2014). In traditional medicinal practice *C. odorata* is posited to be popular for its antifungal, antitrypanosomal, antibacterial activities (Jude *et al.*, 2013; Mohamed and Maruthi, 2013). In the southern part of Nigeria, the leaves of *C. odorata* are used for wound dressing, skin infection and to stop bleeding (Sukanya *et al.*, 2011). The antimicrobial attributes of this plant may be intimately linked to some chemical compounds found in it.

Research studies have revealed the presence of numerous chemical compounds including alkaloids, flavonoids, steroids, phenols, glycosides, terpenoids, steroids, quinones, saponins, triterpenes, hydroxycinnamic acids and lignans in appreciable quantities in the leaves of *C. odorata* (Talapatra *et al.*, 1974 and 1977; Sukanya *et al.*, 2011; Jude *et al.*, 2013; Mohamed and Maruthi, 2013). Previous investigations of the leaves and stems of *C. odorata* also reported the presence of essential oils (Chowdhury, 2002).

It was reported that leaf extract of *C. odorata* possesses bioactive metabolites like phenolics and flavonoids which have been reported to be potent free radical scavengers and antibacterial activity (Nanadin *et al.*, 2014). Luteolin, one of the flavonoids found in the leaf of the plant, according to Dillard and German (2000) has antibacterial, anti-inflammatory, antimutagenic, antioxidant and immune-modulating activities. Quercetin, another flavonoid report to be present in the *C. odorata* leaves has antibacterial, anti-anemic, antiviral, activities (Sen *et al.*, 2005; Lakhanpal and Kumar, 2007; Rigano *et al.*, 2007; Tapas *et al.*, 2008; Chen, 2010).

Phenolics are another group of phytochemical compounds found in the leaves of *C. odorata*. Generally, Phenolics are said to be important for cell structure, signaling and pigmentation (Adyanthaya, 2007). Phenolic acids are known to act as allelochemicals, protecting plants against environmental and biological stress such as high energy radiation exposure, bacterial infection or fungal attacks (Dillard and German, 2000; Yoshioka *et al.*, 2004; Adyanthaya, 2007).

Onother groups of chemical compounds found in the leaves of *C. odorata* are Saponins and Avenacins. These compounds are reported to have broad range of pharmacological properties (Soetan, 2008). Avenacins have antimicrobial properties (Mert Türk *et al.*, 2005; Soetan, 2008). Avenacin A-1 has potent anti-fungal activity (Armah *et al.*, 1999), and is believed to confer resistance against a range of soil fungi (Field *et al.*, 2006).

Research reports stated that Terpenes present in the leaves of *Chromolaena* have antimicrobial, antioxidant, cardiogenic and insecticidal activities (Dillard and German, 2000; Islam *et al.*, 2003; Soetan, 2008). Apigenins a phytochemical compound found also in the leaves of *C. odorata* has antioxidant, hypoglycemic, hepatoprotective, anti-inflammatory, antibacterial, oxygenase inhibitory, and apoptosis inducing activities (Wollen and Roitman, 1996; Dillard and German, 2000; Panda *et al.*, 2010).

*Chromolaena odorata* leaves are reported to contain caffeic acid which is a hydroxycinnamic derivatives that suppresses the expression of type III secretion system (T3SS) genes of the plant pathogen *Dickeya dadantii*, suggesting that *C. odorata* can also defend against bacterial pathogens by manipulating the expression of the T3SS (Yan *et al.*, 2009; Oksana *et al.*, 2012). Also found in *C. odorata* leaves are

4-Hydroxybenzoic acid esters that are reported be widely used as antifungal, anti-mutagenic, antisickling and estrogenic activities and generally used as antimicrobial agents in a large variety of food, pharmaceutical, and cosmetic products (Chong *et al.*, 2009; Khadem and Marles, 2010; Oksana *et al.*, 2012). In plants, the impermeability of the cell wall is increased by p-hydroxybenzoic acid and this leads to increased resistance against pathogen infection (Horvath *et al.*, 2002; Tan *et al.*, 2004). All these compounds may be responsible for the antimicrobial properties of the *C. odorata* used as amendment material in this study.

Bonanomi *et al.* (2009) cited many examples of soil borne pathogens controlled effectively by the application of organic amendment: *Rhizoctonia solani*, *Aphanomyces euteiches*, several species of *Fusarium*, *Verticilium dahlia* and *Gaeumannomyces graminis* (Nuria, *et al.*, 2012), *Pythium* (Lamparter, 2009). This means that there is possibility for these plants (when use as organic amendment) to improve the suppressiveness of the soil after incorporation into the soil thereby enhancing soil health. A soil is regarded as suppressive when, in spite of favourable conditions for disease, a pathogenic organism either cannot become established even if it establishes but produces no disease or establishes and produces disease for a short time and then declines (Monteith, 1990; Kumar *et al.*, 2012).

General suppression is defined as the total microbial biomass in soil which competes with the pathogen for resources or causes inhibition due to antagonistic activity which is enhanced by good fertility of soil or by the addition of organic material which can increase soil microbial activity and other agronomic matter (Rovira and Wildemuth, 1981). Nanadin *et al.* (2014) reported that aqueous extract of *C. odorata* leaves showed

the best antibacterial activities against *Proteus mirabilis*, *Staphylococcus aureus* and *Bacillus megaterium*.

#### **2.1.9 Maize Production in Nigeria**

Maize (*Zea mays*) is a member of the grass family (gramineae). It originated from South and Central America and was introduced to West Africa by the Portuguese in the 10th century (Olaniyi and Adewale, 2012). It is one of the important grains in Nigeria, not only because many farmers engaged in its production, but also because of its economic value.

Nigeria was ranked 10th largest producer of maize in the world, and the largest maize producer in Africa, followed by South Africa (USDA, 2010). Maize is a major important cereal crop being cultivated in many ecological zones of Nigeria particular in the savannah zones. Maize production started as a subsistence crop and has now gradually become a more economically important crop. Maize is now a commercial crop on which many agro-based industries depend on as raw materials (Iken and Amusa, 2004).

Maize is generally easy to produce, highly yielding, easy to process, readily digested and cheaper than other cereals. IITA estimates that approximately 60 percent of maize produced in the Nigeria is used both for human (flour, starch, cornflakes, dextrose, beer, malt drinks, syrup etc) and animal consumption, mainly poultry (USDA, 2010).

Consequently, increasing maize yields and its cultivation particularly in high production potential areas of the country is urgently paramount (Cadoni and Angelucci, 2013; Olaniyan, 2015)

Although maize mean grain yield has increased from 1.6 t/ha in 1981 to 2.0 t/ha in 2009, the limited availability of good quality improved seed, fertilizer and other inputs have minimized the potential yield gains recorded on farm in Nigeria. According to IITA report (2013), maize demand in the country is estimated to increase by 3.2% per year due to perspective growth of urbanization and population. This can only be met when the crop productivity is increased through improvement in soil quality and efficient use of organic manures.

#### **2.1.10 Complementary uses of organic and inorganic manures for crop production**

There is increasing evidence that the most promising way to improve crop yields at a sustainable level, especially in small holder arable farming system in Nigeria, is by increasing inorganic fertilizer use efficiency through the addition of organic amendments (Jones *et al.*, 1997; Badu-Apparaku *et al.*, 2005). The complementary uses of organic and mineral fertilizers have been proved to be sound fertility management strategies in many countries of the world (Olabode *et al.*, 2007).

Other factors that support the combination of organic and inorganic manures are the inability of the small scale farmers to supply sufficient amount of either inorganic or organic amendment, the understanding and the recognition of the fact that both inorganic and organic amendments fulfil a set of different function as well as the potential for creating added benefit when applying two plant nutrients resources

(Vanlauwe *et al.*, 2001; Vanlauwe and Sanginga, 2004). It was reported that nutrients from mineral fertilizer enhance the establishment of crop while those from organic manure promote yield when both fertilizers were combined (Fuch *et al.*, 1970).

Balasubramanian and Nnadi (1990) and Tittone *et al.* (2008) reported that increased and sustained crop yield could be obtained with judicious and balanced N.P.K. fertilizer combined with organic matter amendments. Complementary application of organic and inorganic manures increases nutrient synchrony and reduces loss by converting inorganic nutrient to organic form particularly nitrogen and phosphorus (Kautika *et al.* 2004). In a study conducted by Odunze *et al.* (2012) in upland Ultisols of subtropical China, application of combined inorganic fertilizer and organic matter sequestered significantly higher total carbon, total nitrogen and total phosphorus and resulted in significantly higher maize grain yield than treatments without organic matter input.

Ogundare *et al.* (2014) posited that integrated use of *C. odorata* with urea fertilizer showed promising potentials in conserving soil fertility and improving the yield of maize in Savannah zone of Nigeria and recommended *C. odorata* biomass at 6 t/ha combined with 104 kg/ha of urea fertilizer.

## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

**3.1 Description of the experimental site:** The preliminary and field experiment were conducted at the University of Ilorin Teaching and Research Farm, Bolorunduro (Latitude 8° 29' N and Longitude 4° 30' E) in the Southern Guinea Savannah zone of Nigeria (Abayomi *et al.*, 2006; Olaoye, 2009). The soil has been characterized as an Alfisols (Olaoye and Omuetti, 2006). The rainfall distribution of the location is bimodal with early rain season occurring in the month of April to mid July and late rain from late August to October. The mean annual rainfall ranges between 1100 mm to 1400 mm while the mean daily temperature ranges between 26° and 38° C (Folusho and Olaoye, 2010).

### 3.2 Preliminary Experiment

**Collection of soil samples:** Pre-Planting soil samples were collected randomly at the site of the experiment at the University of Ilorin Teaching and Research farm. Soil samples were taken at 0-30cm depth using hand shovel. A total of twenty (20) samples from different points were randomly taken to ensure that the samples represent the soil in the experimental site.

The randomly collected soil samples were bulked and mixed properly to ensure homogeneity. Samples to be used for laboratory analysis were sub-sampled from the bulk and the rest were used for potted experiment. Samples used for laboratory analysis were sub-sampled from the bulk and transported to the laboratory in fabric soil bags (cloth bags). The soil samples were then air-dried and sieved through 2.00 mm mesh. Four (4) core samples were also collected for bulk density determination.

Before the field experiments in 2014, soil samples were collected as described above and physical and chemical properties analyzed. Soil physical and chemical properties of the experimental site were also determined after harvest in 2014 and 2015 growing seasons.

### **3.2.1 Determination of Physico-chemical properties of the soil**

The indicators selected and measured for soil quality assessment from the preliminary (potted experiment) and field experiment (in 2014 and 2015 growing seasons) were based on recommendation of soil quality researchers (Doran and Parkin, 1994; Wander *et al.*, 2002; Rezaei *et al.*, 2006; Martinez- Salgado *et al.*, 2010), as well as sensitivity of the indicators to soil management (Doran and Jones, 1996; Centu *et al.*, 2007; Dick, 2010).

The soil physico-chemical properties selected and measured as soil quality indicators were: soil texture, structural stability, bulk density, total porosity, water filled pore spaces and soil moisture content; soil pH, organic carbon content, Soil Organic Matter, total Nitrogen, available Phosphorus, exchangeable bases and effective cation exchange capacity; as well as microbial population, diversity and their succession on decomposing *C. odorata*. Methods used for determination of soil properties were as earlier outlined for preliminary experiment.

The following properties of the soil were determined in the laboratory before the experiment.

### (i) **Determination of Soil Physical Properties**

**Particles size analysis:** The particle size was analysed using the hydrometer method (Motsara and Roy, 2008). The percentage clay, silt and sand contents were determined by calculation. Textural triangle was then used to determine textural class of the soil.

**Soil moisture content:** Gravimetric method described by Motsara and Roy (2008) was used. Percentage soil moisture content was calculated thus:

$$\% \text{ Soil moisture content} = \frac{\text{wet soil weight} - \text{oven dried weight}}{\text{oven dried soil weight}} \times 100$$

**Soil bulk density;** This was determined using the core method.

$$\text{Bulk density (g/cm}^3\text{)} = M_s/V.$$

where  $M_s$  is the mass (g) of the oven- dried core soil sample and  $V$  is the total volume ( $\text{cm}^3$ ) of the soil including air and water (Cresswell and Hamilton, 2002)

**Soil Porosity:** This was derived from relationship between bulk density and particle density

$$\% \text{ Total porosity} = \{1 - (B.d/P.d)\} \times 100.$$

Where  $B.d$  is soil bulk density and  $P.d$  is particle density estimated to be  $2.65\text{gcm}^{-3}$  (Cresswell and Hamilton, 2002)

Immediately after the potted experiment, soil bulk density, total porosity and soil moisture content were also determined.

In addition, water filled pore spaces and soil structural stability index of the field before experiment in 2014 and after the experiment in 2015 were calculated using the equations proposed by Weinhold *et al.* (2008) and Reynolds *et al.* (2007) respectively.

% **Water filled pore spaces** (WFPS) =  $\theta_v/TP \times 100$  (Weinhold *et al.*, 2008; Tom, 2013).

Where  $\theta_v$  is % volumetric water content and TP is % total porosity, and

% volumetric water content = % Gravimetric water content X soil bulk density

**Soil Structural Stability index** =  $\frac{1.72 \times \text{O.C (weight \%)}}{\text{Clay + Silt (weight \%)}} \quad (\text{Reynolds } et al., 2007)$

where O.C is soil organic carbon.

## (ii) **Determination of soil Chemical properties**

**Soil pH:** Soil pH was measured using (Soil: H<sub>2</sub>O, 1:2.5 w/v) suspension ratio. Digital pH meter reading was recorded for each sample.

**Organic Carbon determination:** Walkley and Black (1934) method was used to determine organic carbon of the soil sample. The percentage organic carbon was calculated using the formula:

$$\% \text{ Organic carbon} = \frac{(\text{Blank-soil titre value} \times 0.50 \times 0.003 \times 1.33 \times 100)}{\text{g of air dried soil}}$$

**Soil Organic Matter (SOM);** This was calculated from the value of soil organic carbon obtained using equation:

$$\text{SOM} = \text{SOC} \times 1.724$$

This is based on the assumption that Soil Organic Matter contains 58 % organic carbon (Thiagalanga, 2000; Motsara and Roy, 2008).

**Total Nitrogen determination:** Total Nitrogen was determined according to regular Micro-Kjeldahl method described by Chopra and Kanwar (2011).

Calculation:

$$\% N = \frac{T-B \times M \times 1.4}{5} \times 100$$

Where T = Soil titre value

B= Blank titre value

M= Molarity of HCl

5= weight of soil, used for digestion

**Determination of available Phosphorus:** Bray 1 method (Bray and Kurtz, 1945) was used for determination of available Phosphorus.

**Determination of Exchangeable Bases:** Exchangeable bases (K, Ca, Na, Mg) were determined by ammonium acetate method adjusted to pH 7 (Udo *et al.*, 2009). Potassium (K) and Sodium (Na) were determined on a flame photometer while Calcium (Ca) and Magnesium (Mg) were determined on an atomic absorption spectrometer. Effective CEC was thus calculated by the sum of exchangeable bases (Ca, Mg, K and Na) and total acidity (exchangeable Al and H<sup>+</sup>).

**Determination of Exchangeable Acidity:** This was done by titration method described by Epebinue (2000).

### **3.3 Determination of chemical composition of Plant materials (organic amendment materials)**

The chemical composition of the three (3) plants (*Amaranthus spinosus*, *Aspilia africana* and *Chromolaena odorata*) used for amendment of soil was determined. The plants were collected within the University of Ilorin Teaching and Research Farm and other areas within Ilorin township. Confirmation of the plants (Plates 1, 2 and 3) as *Amaranthus spinosus*, *Aspilia africana* and *Chromolaena odorata* was made at the Herbarium of the Plant Biology Department, University of Ilorin, Ilorin with Voucher numbers UILH/003/142, UILH/002/790 and UILH/001/1281 respectively. The plants' biomass (leaves and succulent stems) were oven-dried at 65° C and ground to pass through 0.50mm sieve.

The plant materials were digested with concentrated H<sub>2</sub>SO<sub>4</sub> and the solution was analyzed for essential plant nutrients (Organic carbon, N, P, K, Ca and Mg). Walkley and Black (1934) method was used for organic carbon determination, Kjeldhal colorimetric method was used for total Nitrogen while Vanado-molybdate yellow method was adopted for determination of total Phosphorus in plant samples. Atomic Absorption Spectrometer was used for determination of Ca and Mg, while K was analyzed with Flame Photometer (Motsara and Roy, 2008).



**Plate 1: *Amaranthus spinosus* (L.)**



**Plate 2: *Aspilia africana* (PERS) Adams**



**Plate 3: *Chromolaena odorata* (L.) KING and ROBINSON**

**a: Chromolaena at Vegetative stage**

**b: Chromolaena at flowering stage**

### **3.4 Potted Experiment**

#### **3.4.1 Experimental Design**

Potted experiment was conducted in the screenhouse of Agronomy Department, University of Ilorin Teaching and Research Farm, between May and August, 2014. The experiment was laid out as a Complete Randomized Design (CRD) and replicated three (3) times. The treatments are presented in Table 1.

The rates (5% and 7.5%) each of *A. spinosus*, *A. africana* and *C. odorata* were used. This is equivalent to 10t/ha and 15t/ha respectively and match realistic production rates prescribed by Ibewiro *et al.* (2000) and Tian *et al.* (2000) for natural or managed system. The organic amendments were chopped and incorporated into plastic pots, containing 10 kg of soil each, two (2) weeks before planting of the test crop (maize) for synchronization of nutrients uptake with mineralization. Mineral fertilizer at the rate of 60: 30: 15 Kg/ha NPK and 120: 60: 30 Kg/ha NPK represents 50 and 100% respectively recommended dosage for the maize production in Guinea Savannah ecological zone (Akintude *et al.*, 1993; Olaniyan and Lucas, 2004) were also set up to form other treatments. The maize variety used for potted experiment was DMR- LSR yellow obtain from IITA, Ibadan.

**Table 1: Treatment combinations for potted experiment**

| Treatments | Soil amendments                                         | Rates of application      |
|------------|---------------------------------------------------------|---------------------------|
| 1          | <i>Amaranthus spinosus</i>                              | 5%                        |
| 2          | <i>Amaranthus spinosus</i>                              | 7.5%                      |
| 3          | <i>Aspilia africana</i>                                 | 5%                        |
| 4          | <i>Aspilia africana</i>                                 | 7.5%                      |
| 5          | <i>Chromolaena odorata</i>                              | 5%                        |
| 6          | <i>Chromolaena odorata</i>                              | 7.5%                      |
| 7          | <i>Amaranthus</i> + <i>Aspilia</i>                      | 5%                        |
| 8          | <i>Amaranthus</i> + <i>Aspilia</i>                      | 7.5%                      |
| 9          | <i>Amaranthus</i> + <i>Chromolaena</i>                  | 5%                        |
| 10         | <i>Amaranthus</i> + <i>Chromolaena</i>                  | 7.5%                      |
| 11         | <i>Aspilia</i> + <i>Chromolaena</i>                     | 5%                        |
| 12         | <i>Aspilia</i> + <i>Chromolaena</i>                     | 7.5%                      |
| 13         | <i>Amaranthus</i> + <i>Aspilia</i> + <i>Chromolaena</i> | 5%                        |
| 14         | <i>Amaranthus</i> + <i>Aspilia</i> + <i>Chromolaena</i> | 7.5%                      |
| 15         | Mineral Fertilizer                                      | NPK -60:30:15<br>(Kg/ha)  |
| 16         | Mineral Fertilizer                                      | NPK -120:60:30<br>(Kg/ha) |
| 17         | Control (No amendment)                                  | --                        |

### 3.4.2 Data collected on maize performance on the potted experiment

(a) **Plant Height:** This was taken from the three pots representing each treatment. A metric tape was used for measuring the height from the soil surface in the pot to the arch of the upper most leaf that was at least 50% emerged from the whorl (Bob-Nielsen, 2003). The mean plant height from the three pots was determined for each treatment. This was done at two (2) weeks intervals starting from 2 week after sowing (WAS).

(ii) **Number of leaves:** Visual counting of leaves of maize plant in each pot was made at two weeks intervals and the number was recorded.

(v) **Grain yield (kg/plant):** This was determined after the sun-dried cob (s) harvested from maize plant in the pot were shelled and their weights measured.

(vi) **% Relative yield increase at each treatment level.** This was obtained from the equation proposed by Fening *et al.* (2009):

$$\% \text{ Relative yield increase} = \frac{\text{Yield of treatment} - \text{Yield of control}}{\text{Yield of control}} \times 100$$

### 3.4.3 Microbial analysis of soil amended with *Chromolaena odorata* in potted experiment

Laboratory analysis of soil samples were carried out to determine microbial population, diversity and succession in soil amended with *C. odorata*. Microbial load of the soil sample was determined using serial dilution method. Soil fungi and bacteria at 0, 2, 4, 6, and 8 weeks after treatments were enumerated. Potato Dextrose Agar (PDA) medium supplemented with 1% streptomycin was used for isolation of fungi in

soil while nutrient Agar (NA) medium was used for isolation of bacteria in soil, Mackonkey Agar was used for enumeration of coliform bacteria and Eosin methylene blue agar was used for enumeration of faecal coliform bacteria. The culture media were prepared according to the manufacturers' instructions and sterilized by autoclaving at 120°C and pressure of 1.05kg/cm<sup>3</sup> for 15minutes. The media were allowed to cool to 45°C before pouring aseptically into the Petridishes.

Ten grams (10g) each of soil sample was mixed with 90 ml of sterile (distilled) water in a conical flask. The suspension was shaken for 30 minutes with mechanical shaker. Ten folds serial dilution of soil suspension were made in sterile water. Bacteria were isolated by plating 1ml of 10<sup>-5</sup> dilution in sterile nutrient Agar (NA) using pour plate method while fungi isolation was by plating one (1) ml of 10<sup>-3</sup> dilution in sterile Potato Dextrose Agar (PDA) medium supplemented with 1% streptomycin. Inoculated plates were inverted in an incubator at 37°C for 18-24hours for bacteria and 28±2°C for 3-5days for fungi. Each treatment was made in three (3) replicates. Total number of colony forming units (cfu) obtained per plate was recorded. Means of replicate treatments were calculated and total count per gram of soil estimated was multiplied with the dilution factor.

Fungi isolated were identified using cultural and microscopic characteristics. Colony morphology used include: colour of spores, elevation and nature of mycelia as well as presence or absence of pigments. The microscopic features employed for fungi identification were; type and shape, sexual and asexual spores, presence or absence of cross walls (i.e. septate or aseptate), shape of conidiophores, presence or absence of sterigmata, presence of sporangiospores, chlamydospores, etc.

Some morphological, physiological and biochemical tests were employed in identification of bacteria. These include gram reactions of bacteria cells, shape and arrangement of cells and sugar fermentation test. Bergey's manual of determinative bacteriology was used to confirm the identity of the bacterial species as described by John (1994).

### **3. 5 Field experiments**

The experiments were conducted during 2014 and 2015 growing seasons at University of Ilorin Teaching and Research Farm, to examine the effect of soil amendments with *Chromolaena odorata* biomass and mineral fertilizer on soil quality Improvement and maize performance.

#### **3. 5. 1 Experimental Design**

The field layout was 3 x 6 factorial arranged in randomized complete block design (RCBD), consisting of three (3) maize varieties (DMR-LSR, Oba 98 and Oba super 2) and six soil treatments, replicated three times. DMR- LSR was obtained from IITA, Ibadan while Oba 98 and Oba super 2 were purchased at Premier seed shop along Agric-Zango raod, Ilorin.

#### **3. 5. 2 Land preparation and Planting**

The land was ploughed, harrowed and ridged for a good seed bed before the first planting in 2014 growing season. The field was then marked into plots. The total land area used was 54m x 30m (1620m<sup>2</sup>) with 0.5m alleyways between plots and 1m between blocks. The size of each plot was 4m x 5m (20m<sup>2</sup>).

### 3. 5.3 Application of amendment materials and other Agronomic practices

Although the three organic amendments were generally high in nutrient contents based on results of the preliminary study, the resource quality of *C. odorata* was preferred because of other advantages it has over *A. spinosus* and *A. africana*. These include large biomass production, ease of propagation, fast decomposition rate as well as availability, in abundance, in most farm vicinity in this ecological zone (Quansah *et al.*, 2001). *Chromolaena odorata* was therefore used as organic amendment for field studies. It was applied at the rate of 10 and 15 t/ha immediately after ridging. The chopped leaves and succulent stems of the materials were used to avoid weed infestation. Maize seeds were sown two (2) weeks after organic amendment application at 1mx 0.5m at 2 seeds per hill to give an approximate population of 40,000 plants per hectare.

Mineral fertilizer was applied to the designated plots at the recommended rate NPK: 120: 60:30 kg/ha (Akintude *et al.*, 1993; Olaniyan and Lucas, 2004). This rate also coincides with the rate recommended by seed producer of the maize varieties used as test crop (Premier Seed) in Southern Guinea Savannah zone of Nigeria. The application was done in split doses- two weeks and six weeks after plant emergence. Also 50% of this rate (NPK: 60: 30:15 kg/ha) was used in combination with 10 and 15 t/ha of *C. odorata* for another set of designated plots. A summary of treatment combinations and field layout is presented in Table 2. Weeding was done manually at 2, 5 and 7 WAS during the two seasons. During the second growing season (2015), reduced tillage was adopted to ensure minimum soil disturbance.

**Table 2: Maize varieties and soil Treatments**

| <b>Maize Varieties</b>                                        | <b>Attributes</b>                                        | <b>Code</b> |
|---------------------------------------------------------------|----------------------------------------------------------|-------------|
| DMR-LSR (Yellow)                                              | Downy Mildew and Streak Resistant (Open Pollinated)      | V1          |
| Oba 98 (White)                                                | High yield, quality protein white maize (Hybrid)         | V2          |
| Oba Super 2 (Yellow)                                          | High yield, short stature, resistant to lodging (Hybrid) | V3          |
| <b>Soil Treatments</b>                                        |                                                          |             |
| <i>Chromolaena odorata</i> (10 t/ha)                          |                                                          | T1          |
| <i>Chromolaena odorata</i> (15 t/ha)                          |                                                          | T2          |
| Mineral Fertilizer (NPK -120: 60: 30 Kg/ha)                   |                                                          | T3          |
| <i>Chromolaena odorata</i> (10 t/ha) + (NPK- 60: 30:15 Kg/ha) |                                                          | T4          |
| <i>Chromolaena odorata</i> (15 t/ha) + (NPK-60: 30:15 Kg/ha)  |                                                          | T5          |
| Control (No amendment)                                        |                                                          | T6          |

#### 3.5.4 Data collected on maize performance on the field experiment

(i) **Plant Height (cm):** This was taken from sample of eight (8) randomly selected maize plants marked within each plot. A metric tape was used for measuring the height from the soil surface to the arch of the upper most leaf that was at least 50% emerged from the whorl (Bob- Nielsen, 2003). The mean of plants height from each plot was determined. This was done at two (2) weeks intervals starting from 2 WAS.

(ii) **Number of leaves:** Visual counting of leaves on the eight randomly selected plants was made at two weeks intervals and the number was recorded for each plant. The mean values were then calculated for each plot.

(iii) **Leaf area:** The leaf area was determined by the non destructive (length x width) method using the equation;

**Leaf area** = Ear leaf length x leaf width at the broadest point x 0.75

where 0.75 is a constant. Lengths of eight leaves each from each plot were measured with a meter rule and measuring tape. Ruler was used to measure leaf diameter at its broadest point and tape for leaf length. The values were then averaged. Leaf area was determined at 6 WAS as prescribed by Onasanya *et al.* (2009).

(iv) **Number of cobs per plot:** The total cobs harvested from each plot was counted and recorded for each plot after sundrying to 13 - 14% moisture content. The average for plot was determined.

(v) **Grain weight per cob (g/cob):** Total grain weight of each plot divided by total number of cobs obtained from the plot.

(vi) **Grains weight per plot (kg/plot)**: The weight of the grains from the cobs harvested from each plot was determined separately and then averaged for each plot.

(vii) **Biological Yield (t/ha)**: This was obtained by sundrying maize plant along with ears. It is given by total weight of plant dried matter (kg) divided by area of the plot from where the plant was harvested ( $\text{m}^2$ )  $\times 10$  (i.e. 10,000/1000)

(viii) **Grain Yield (t/ha)**: This was calculated using equation:

$$\text{Grain Yield (t/ha)} = \frac{\text{Grain weight (kg)}}{\text{Area of the plot (4m x 5m)}} \times 10 \quad (\text{Singh and Singh, 2011})$$

$$(ix) \text{ **Harvest index (H.I)** } = \frac{\text{Grain Yield (Economic yield)}}{\text{Biological yield}} \times 100 \quad (\text{Reddy, 2004})$$

(x) **Weight of 1000 grains (g)**: One thousand (1000) maize grains were randomly counted from each plot and weighed.

### 3.5.5 Data Analysis

Data collected were subjected to statistical analysis using IBM SPSS (Version 20) statistical package. The treatment means were separated using new Duncan's Multiple Range Test (NDMRT) at  $P \leq 0.05$ . Coefficients of correlation among some soil properties such as; soil organic carbon, Soil Organic Matter, total N, available P, Ca, Mg, K, and CEC as well as among some yield parameters such as; number of cobs/plot, cobs weight/plot (kg/plot), biological yield (t/ha), grain yield (t/ha), weight of 1000 seeds (g), harvest index, and leaf area index were also calculated using Pearson product moment correlation method.

## **CHAPTER FOUR**

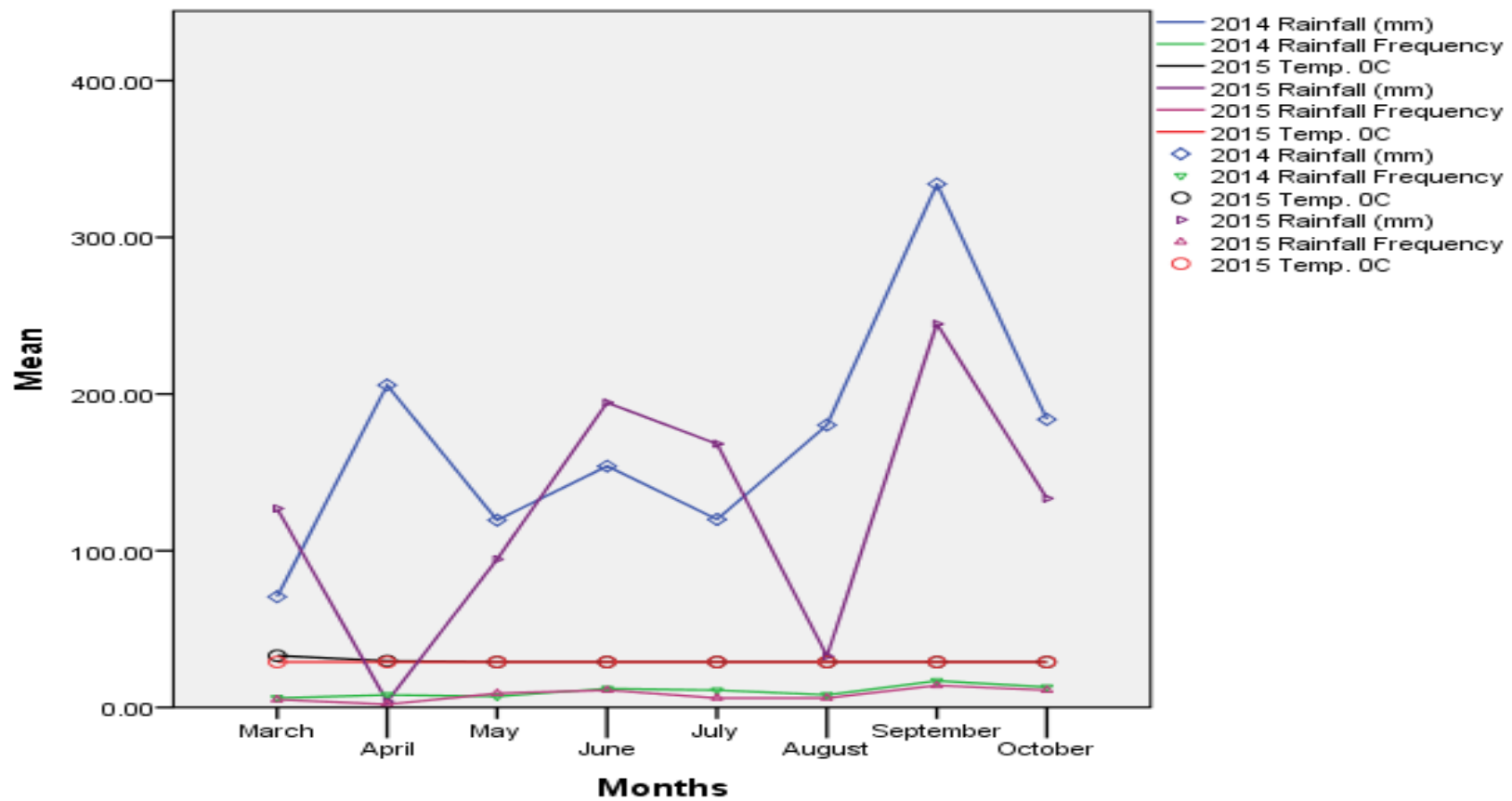
### **4.0 RESULTS AND DISCUSSION**

Figure 1, showed rainfall distribution and temperature in 2014 and 2015 growing seasons at the experimental site. The rainfall intensity was higher in May and August (cropping period) in 2014 relative to the one recorded in 2015. However, rainfall intensity in the months of June and July in 2015 was higher compared to the one recorded in 2014. The total amount of rainfall during the four cropping months in 2014 was 573.70 mm while total rainfall intensity was 490 mm in 2015. There was no much variation on the temperature and rainfall distribution in 2014 and 2015 (Figure 1). These may therefore not have significant effect on the results of this study.

#### **4.1.1 Soil quality status before the preliminary experiment**

The physico-chemical properties of the soil used for potted experiment in 2014 are presented in Table 3. The soil was low in major soil macro nutrients with total N (1.62 g/kg), available P (6.12 mg/kg), exchangeable Ca (1.36 cmol/kg) and exchangeable K (0.14 cmol/kg), all at the critical level. Also soil organic carbon (4.46 g/kg) and Soil Organic Matter (7.67 g/kg) as well as Effective CEC (2.20 cmol/kg) were at a very low levels.

The particle size analysis of the soil also revealed that the soil is loamy sand with clay content below 10% (70 g/kg) and structural stability index below 7% (5.36%). All these point to the low quality of the soil used for the potted experiment and the need to improve its fertility for meaningful crop yield. However, the soil had a moderate acidic condition (pH 6.57) indicating that soil pH was not a limiting factor in the experiment.



**Figure 1:** Rainfall intensity, rainfall frequency and and temperature in 2014 and 2015 growing seasons at the experimental site.

**Table 3: Physico-Chemical properties of the surface soil used for potted experiment in 2014**

| <b>Soil Physical Properties</b>       | <b>Value</b> |
|---------------------------------------|--------------|
| Sand (g/kg)                           | 857          |
| Silt (g/kg)                           | 73           |
| Clay (g/kg)                           | 70           |
| Textural Class                        | Loamy sand   |
| Structural Stability (%)              | 5.36         |
| Bulk density (g/cm <sup>3</sup> )     | 1.41         |
| Porosity (%)                          | 46.79        |
| <b>Soil Chemical Properties</b>       | <b>Value</b> |
| Soil pH(H <sub>2</sub> O :1 :2.5 w/v) | 6.57         |
| Soil organic carbon (g/kg)            | 4.46         |
| Soil organic matter (g/kg)            | 7.67         |
| Total nitrogen (g/kg)                 | 1.62         |
| Available phosphorus (mg/kg)          | 6.12         |
| Calcium (cmol/kg)                     | 1.36         |
| Magnesium (cmol/kg)                   | 0.32         |
| Potassium (cmol/kg)                   | 0.14         |
| Sodium (cmol/kg)                      | 0.2          |
| ECEC (cmol/kg)                        | 2.2          |

Generally, the low nutrient contents of the soil recorded may be associated with its high sand content. Sandy soils in Guinea Savannah zone have been reported to be mostly infertile as they are characterized by low organic matter content, deficiency in available phosphorus and plant nutrients contents along with the presence of low activity clay (Juo *et al.*, 1995; Jerome *et al.*, 2013). This thus implies that crop grown on such a soil will respond to soil amendment. Low carbon and clay content (surface fine fraction) recorded also suggest poor nutrients and water holding capacity of the soil since the finer the soil texture the higher its ability to hold or retain water for plant use (Gardner, *et al.*, 2001; Aminoullah *et al.*, 2014).

#### **4.1.2 Nutritional composition of organic amendments used for the potted experiment**

The relatively high content in basic plant nutrients of the three amendment materials used in this study coupled with low C/N ratio ( $< 20$ ) as shown in Table 4, suggests that important plant nutrients like nitrogen and phosphorus are not likely to be immobilized by soil microbes during the decomposition process of organic amendments (Manzoni *et al.*, 2010). They can therefore be regarded as high quality organic resources that can be used as organic amendments (Daudu *et al.*, 2005). However, the results showed that *A. spinosus* was superior to the other amendments in terms of N, P, Mg, and K content while *C. odorata* was superior to others in Ca and organic C contents. *A. africana* has, relatively, the least plant nutrients content.

**Table 4: Chemical composition of the weeds (leaves and succulent stems) used as amendment in the potted experiment.**

| <b>Chemical Constituents</b> | <b><i>Amaranthus spinosus</i></b> | <b><i>Aspilia africana</i></b> | <b><i>Chromolaena odorata</i></b> |
|------------------------------|-----------------------------------|--------------------------------|-----------------------------------|
| Organic Carbon (g/kg)        | 56.90                             | 32.30                          | 179.10                            |
| Total Nitrogen (g/kg)        | 31.50                             | 20.20                          | 24.60                             |
| Phosphorus (g/kg)            | 15.25                             | 2.63                           | 8.42                              |
| Calcium (g/kg)               | 25.25                             | 41.50                          | 61.00                             |
| Magnesium (g/kg)             | 34.40                             | 17.60                          | 23.30                             |
| Potassium (g/kg)             | 21.81                             | 8.46                           | 9.35                              |
| Carbon: Nitrogen ratio (C/N) | 2                                 | 2                              | 7                                 |

#### **4.1.3 Effect of soil amendments on maize plant height in potted experiment**

The mean plant heights of maize in treatments containing organic amendments were significantly ( $p \leq 0.05$ ) higher than those in the control at 4, 6 and 8 WAS (Table 5). The lower values of mean plant height recorded in control plots (plots with no amendment) may be attributed to the low plant nutrients content of the soil. Plants growing on soil with low plant nutrients are characterized with poor root development and subsequent poor water and nutrients uptake (Osunbitan *et al.*, 2005). This may be responsible for low plant height recorded in control pots.

#### **4.1.4 Effect of soil amendments on maize number of leaves in potted experiment**

Mean number of leaves per plant recorded from pots with soil amendment were significantly ( $p \leq 0.05$ ) higher than those from control pots at 6 and 8 WAS (Table 6). The higher number of leaves recorded on the plots with soil amendment compared to those without any amendment (control) may be due to better vegetative growth accomplished by more plant nutrients supplied by soil amendments.

#### **4.1.5 Yield response of maize plants to different rates of Soil amendments in potted plant experiment**

Mean yields of maize plants in pots with organic amendments at 7.5% rate gave significantly higher yield ( $p \leq 0.05$ ) compared to mineral fertilizer and control, except in pots with *A. africana* and in pots containing *A. spinosus* + *A. africana* + *C. odorata* (Table 7). However the highest mean yield (72.40 g/pot) was obtained from pots amended with *Chromolaena odorata* at 7.5% rate of application. Highest mean relative yield was also observed on the pots amended with *C. odorata* (102.97%). This was

**Table 5: Effect of Soil amendments on maize plant height in Potted Experiment**

| Soil treatments                           | Rates of application    | Mean plant Height (cm) |         |            |           |
|-------------------------------------------|-------------------------|------------------------|---------|------------|-----------|
|                                           |                         | 2 WAS                  | 4 WAS   | 6 WAS      | 8 WAS     |
| <i>Amaranthus spinosus</i>                | 5 %                     | 31.33abc               | 64.00bc | 134.67abc  | 176.00abc |
| <i>Amaranthus spinosus</i>                | 7.5 %                   | 38.00a                 | 91.67a  | 142.00abc  | 179.00abc |
| <i>Aspilia africana</i>                   | 5 %                     | 31.33abc               | 71.33ab | 114.33cd   | 135.67d   |
| <i>Aspilia africana</i>                   | 7.5 %                   | 34.67ab                | 84.66ab | 126.33ab   | 152.33cd  |
| <i>Chromolaena odorata</i>                | 5 %                     | 32.00abc               | 84.33ab | 130.67abc  | 167.00abc |
| <i>Chromolaena odorata</i>                | 7.5 %                   | 38.67a                 | 90.67a  | 154.67a    | 180.67ab  |
| <i>Amaranthus + Aspilia</i>               | 5 %                     | 29.33abc               | 77.67ab | 118.67bcd  | 159.00bcd |
| <i>Amaranthus + Aspilia</i>               | 7.5 %                   | 33.33ab                | 80.33ab | 139.33abc  | 167.33abc |
| <i>Amaranthus + Chromolaena</i>           | 5 %                     | 24.67bc                | 83.33ab | 152.33a    | 179.33abc |
| <i>Amaranthus + Chromolaena</i>           | 7.5 %                   | 32.00abc               | 91.33a  | 155.00a    | 188.67a   |
| <i>Aspilia + Chromolaena</i>              | 5 %                     | 24.67bc                | 74.00ab | 131.67abc  | 172.67abc |
| <i>Aspilia + Chromolaena</i>              | 7.5 %                   | 24.00bc                | 81.67ab | 150.00bc   | 174.33abc |
| <i>Amaranthus + Aspilia + Chromolaena</i> | 5 %                     | 24.67bc                | 72.33ab | 129.33abc  | 167.66abc |
| <i>Amaranthus + Aspilia + Chromolaena</i> | 7.5 %                   | 33.00ab                | 73.67ab | 123.67abcd | 153.33bcd |
| Mineral Fertilizer                        | NPK (60: 30: 15 kg/ha)  | 24.33bc                | 45.33cd | 94.00de    | 135.00d   |
| Mineral Fertilizer                        | NPK (120: 60: 30 kg/ha) | 24.67bc                | 76.00ab | 114.67cd   | 155.33bcd |
| Control                                   | No amendment            | 24.00bc                | 38.33d  | 50.33f     | 69.67e    |
| SE                                        |                         | 0.95                   | 2.42    | 3.96       | 4.12      |

Means followed by the same letter(s) along the same column are not significantly different by NDMRT  $P \leq 0.05$

**Table 6: Effect of soil amendments on number of leaves of maize plant in potted Experiment**

| Soil treatments                           | Rate of application     | <u>Mean number of leaves per pot</u> |        |         |            |
|-------------------------------------------|-------------------------|--------------------------------------|--------|---------|------------|
|                                           |                         | 2WAS                                 | 4WAS   | 6 WAS   | 8 WAS      |
| <i>Amaranthus spinosus</i>                | 5 %                     | 4.67bcd                              | 7.66ab | 9.67abc | 10.67cde   |
| <i>Amaranthus spinosus</i>                | 7.5 %                   | 6.00ab                               | 8.67a  | 10.33ab | 10.67cde   |
| <i>Aspilia africana</i>                   | 5 %                     | 5.60bcd                              | 8.00a  | 9.33ab  | 11.00bcde  |
| <i>Aspilia africana</i>                   | 7.5 %                   | 6.00ab                               | 6.33bc | 10.33ab | 11.33abcd  |
| <i>Chromolaena odorata</i>                | 5 %                     | 6.67a                                | 8.67a  | 10.33ab | 12.00ab    |
| <i>Chromolaena odorata</i>                | 7.5 %                   | 6.00ab                               | 8.67a  | 11.00a  | 12.33a     |
| <i>Amaranthus + Aspilia</i>               | 5 %                     | 6.00ab                               | 8.67a  | 10.67ab | 11.00bcde  |
| <i>Amaranthus + Aspilia</i>               | 7.5 %                   | 6.67a                                | 8.33a  | 10.33ab | 11.67abc   |
| <i>Amaranthus + Chromolaena</i>           | 5 %                     | 7.00a                                | 8.33a  | 10.67ab | 11.67 abc  |
| <i>Amaranthus + Chromolaena</i>           | 7.5 %                   | 6.00ab                               | 8.00a  | 10.00ab | 11.33 abcd |
| <i>Aspilia + Chromolaena</i>              | 5 %                     | 6.00ab                               | 7.67ab | 10.33ab | 10.67cde   |
| <i>Aspilia + Chromolaena</i>              | 7.5 %                   | 6.67a                                | 7.66ab | 10.00ab | 11.00bcde  |
| <i>Amaranthus + Aspilia + Chromolaena</i> | 5 %                     | 5.00bcd                              | 9.33a  | 10.33ab | 12.00ab    |
| <i>Amaranthus + Aspilia + Chromolaena</i> | 7.5 %                   | 5.00bcd                              | 8.67a  | 10.33ab | 11.00 bcde |
| Mineral Fertilizer                        | NPK (60:30:15) kg/ha)   | 4.33cd                               | 6.33bc | 7.00cd  | 10.33de    |
| Mineral Fertilizer                        | N PK (120:60:30) kg/ha) | 5.00bcd                              | 8.33a  | 9.00a   | 10.67cde   |
| Control (No amendment)                    |                         | 4.33cd                               | 5.33c  | 6.33d   | 6.67f      |
| SE                                        |                         | 0.19                                 | 0.24   | 0.27    | 0.29       |

Means followed by the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 7: Effect of Soil amendments on maize grain yield (g/pot) in the potted experiment**

| <b>Treatments</b>                     | <b>Rate of application</b> | <b>Yield (g/pot)</b> | <b>Ralative Yield increase (%)</b> |
|---------------------------------------|----------------------------|----------------------|------------------------------------|
| <i>Amaranthus spinosus</i>            | (5%)                       | 58.67abcd            | 64.48                              |
| <i>Amaranthus spinosus</i>            | (7.5%)                     | 64.16abc             | 79.87                              |
| <i>Aspilia africana</i>               | (5%)                       | 55.87bcde            | 56.63                              |
| <i>Aspilia africana</i>               | (7.5%)                     | 57.87abcd            | 62.24                              |
| <i>Chromolaena odorata</i>            | (5%)                       | 61.98abcd            | 73.76                              |
| <i>Chromolaena odorata</i>            | (7.5%)                     | 72.40a               | 102.97                             |
| <i>Amaranthus + Aspilia</i>           | (5%)                       | 59.33abcd            | 66.33                              |
| <i>Amaranthus + Aspilia</i>           | (7.5%)                     | 64.33abc             | 80.35                              |
| <i>Amaranthus +Chromolaena</i>        | (5%)                       | 56.22bcde            | 57.61                              |
| <i>Amaranthus +Chromolaena</i>        | (7.5%)                     | 71.23ab              | 99.69                              |
| <i>Aspilia +Chromolaena</i>           | (5%)                       | 58.53abcd            | 64.09                              |
| <i>Aspilia +Chromolaena</i>           | (7.5%)                     | 67.13ab              | 88.20                              |
| <i>Amaranthus+Aspilia+Chromolaena</i> | (5%)                       | 53.29cdef            | 49.40                              |
| <i>Amaranthus+Aspilia+Chromolaena</i> | (7.5%)                     | 64.00abc             | 79.42                              |
| Mineral Fertilizer                    | NPK (60:30:15 kg/ha)       | 42.13efg             | 18.11                              |
| Mineral Fertilizer                    | NPK (120:60:30 kg/ha)      | 46.33defg            | 29.89                              |
| Control                               | No amendment               | 35.67g               | -                                  |
| SE                                    |                            | 1.66                 |                                    |

Means with the same letter(s) along the same column are not significantly different at  $P \leq 0.05$  by NDMRT

followed by the mean yields obtained from the mixture of *A. spinosus* + *C. odorata* (99.69%) and mixture of *A. africana* + *C. odorata* (88.20%) in that order.

The higher yield performance recorded in the pots containing organic soil amendment at 7.5% rate of application may be attributed to lower bulk density, higher total porosity and better soil moisture content associated with soils amended with organic residues (Table 8). These might have resulted in better plant roots development and penetration for proper water and nutrients uptake. Ogban *et al.* (2008) affirmed that soil amendment with organic residue improved Soil Organic Matter content, formation of stable soil aggregates and reduced soil bulk density.

#### **4.1.6 Effect of soil amendments on soil physical properties in potted experiment**

All amendment materials relatively improved soil moisture content except soils containing 5% *A. africana* and those with mineral fertilizer (Table 8). The mean values of moisture content ranged from 42.47 to 60.97g/kg. The mean values of soil moisture content in soil amended with mineral fertilizer and *A. africana* (5%) were not significantly ( $p \leq 0.05$ ) different from control. However, soils containing *C. odorata* at 7.5% gave the highest mean value for moisture content which was significantly higher than those of other amendment materials. Soil amendment significantly lowered soil bulk density compared to soils with mineral fertilizer and the control.

Soil porosity showed a similar trend as soil bulk density. Total porosity was inversely related to soil bulk density. Hence soils containing *C. odorata* (at 5% and 7.5%) had means total porosity that were significantly ( $p \leq 0.05$ ) higher than others. Generally, all soils amended with organic amendments had significantly higher total porosity than those with mineral fertilizer as well as those of control.

**Table 8: Effect of soil amendments on soil physical properties after potted experiment**

| <b>Soil treatments</b>                                         | <b>Moisture content (g/kg)</b> | <b>Bulk density (g/cm<sup>3</sup>)</b> | <b>Total Porosity (%)</b> |
|----------------------------------------------------------------|--------------------------------|----------------------------------------|---------------------------|
| <i>Amaranthus spinosus</i> (5%)                                | 45.96ef                        | 1.45bcd                                | 45.28bcd                  |
| <i>Amaranthus spinosus</i> (7.5%)                              | 50.70d                         | 1.45bcd                                | 45.41bcd                  |
| <i>Aspilia africana</i> (5%)                                   | 43.12g                         | 1.50d                                  | 43.40d                    |
| <i>Aspilia africana</i> (7.5%)                                 | 46.73e                         | 1.48cd                                 | 44.15bcd                  |
| <i>Chromolaena odorata</i> (5%)                                | 53.61c                         | 1.40ab                                 | 47.17a                    |
| <i>Chromolaena odorata</i> (7.5%)                              | 60.97a                         | 1.36a                                  | 48.73a                    |
| <i>Amaranthus</i> + <i>Aspilia</i> (5%)                        | 48.13e                         | 1.47bcd                                | 44.53cd                   |
| <i>Amaranthus</i> + <i>Aspilia</i> (7.5%)                      | 53.02c                         | 1.44bcd                                | 45.79bcd                  |
| <i>Amaranthus</i> + <i>Chromolaena</i> (5%)                    | 54.64c                         | 1.43abc                                | 46.04bc                   |
| <i>Amaranthus</i> + <i>Chromolaena</i> (7.5%)                  | 57.54b                         | 1.43abc                                | 46.79bc                   |
| <i>Aspilia</i> + <i>Chromolaena</i> (5%)                       | 53.33c                         | 1.45bcd                                | 45.41bcd                  |
| <i>Aspilia</i> + <i>Chromolaena</i> (7.5%)                     | 56.62b                         | 1.43abc                                | 46.04bc                   |
| <i>Amaranthus</i> + <i>Aspilia</i> + <i>Chromolaena</i> (5%)   | 56.95b                         | 1.47bcd                                | 44.53bcd                  |
| <i>Amaranthus</i> + <i>Aspilia</i> + <i>Chromolaena</i> (7.5%) | 56.23b                         | 1.46bcd                                | 44.78bcd                  |
| Mineral Fertilizer NPK (60:30:15 kg/ha)                        | 42.79g                         | 1.59e                                  | 40.00e                    |
| Mineral Fertilizer NPK (120:60:30 kgN/ha)                      | 42.47g                         | 1.60e                                  | 39.62e                    |
| Control (No amendment)                                         | 42.47g                         | 1.60e                                  | 39.62e                    |
| SE                                                             | 0.26                           | 0.03                                   | 1.14                      |

Means followed by the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

Lower bulk density recorded in *C. odorata* may be due to high percentage content of tissue carbon. Relative high bulk density observed in some soils amended with mineral fertilizer and control may be attributed to the coarse texture of the top soil as a result of low clay and organic matter contents. Soils with coarse textured surface as a result of low Soil Organic Matter content are reported to be vulnerable to lose physical quality and become compacted with ease Adesodun *et al.* (2015). According to Osunbitan *et al.* (2005), this may lead to poor root development and difficulty in nutrients and water uptake by crop.

#### **4.2.1 Biochemical characterisation of bacterial isolates from soil amended with *C. odorata***

*Bacillus*, *Streptococcus*, *Pseudomonas*, *Serratia*, *Proteus* and *Enterobacter* species were the major bacteria isolated from the soil of experimental site (Table 9). These bacteria were either indigenous bacteria that were originally present in the experimental site (*Bacillus*, *Pseudomonas*, *Proteus* and *Enterobacter* species.) or found their way to the soil through human or animal faeces (*Streptococcus* and *Serratia* species.).

The major fungi isolated from soil samples amended with *C. odorata* were *Rhizopus stolonifer*, *Aspergillus niger*, and *A. flavus* (Table 10). However, *Penicillium chrysogenum* was either completely absent in the soil or its population was too low to be captured during microbial load determination before soil amendment. It was however isolated two weeks after the soil was amended with *C. odorata*.

**Table 9: Morphological and Biochemical characteristics of bacterial isolates from soil amended with *Chromolaena odorata***

| <b>Characteristics</b>   |                     |                          |                        |                     |                    |                         |
|--------------------------|---------------------|--------------------------|------------------------|---------------------|--------------------|-------------------------|
| <b>Colony</b>            |                     |                          |                        |                     |                    |                         |
| <b>Morphology</b>        | <b>Isolate A</b>    | <b>Isolate B</b>         | <b>Isolate C</b>       | <b>Isolate D</b>    | <b>Isolate E</b>   | <b>Isolate F</b>        |
| Shape                    | Irregular           | Circular                 | Irregular              | Circular            | Irregular          | Circular                |
| Edge                     | Lobate              | Entire                   | Entire                 | entire              | Lobate             | entire                  |
| Pigmentation             | Creamy              | Creamy                   | Bluish green           | Reddish             | Creamy             | Creamy                  |
| Consistency              | Butyrous            | Butyrous                 | Viscid                 | Butyrous            | Viscid             | Butyrous                |
| Elevation                | Flat                | Raised                   | Flat                   | Raised              | Flat               | Raised                  |
| Colony surface           | Smooth              | Smooth                   | Smooth                 | Smooth              | Smooth             | Smooth                  |
| Optics                   | Opaque              | Opaque                   | Translucent            | Opaque              | Translucent        | Opaque                  |
| <b>Cellular</b>          |                     |                          |                        |                     |                    |                         |
| <b>Morphology</b>        |                     |                          |                        |                     |                    |                         |
| Gram reaction            | +                   | +                        | -                      | -                   | -                  | -                       |
| Motility test            | +                   | -                        | +                      | +                   | +                  | +                       |
| <b>Oxygen</b>            |                     |                          |                        |                     |                    |                         |
| <b>relationship</b>      | FA                  | FA                       | FA                     | FA                  | AE                 | FA                      |
| MRVP test                | +                   | -                        | -                      | +                   | +                  | +                       |
| Oxidase test             | -                   | +                        | -                      | -                   | -                  | -                       |
| Starch hydrolysis        | +                   | +                        | -                      | -                   | -                  | -                       |
| Indole test              | -                   | -                        | -                      | -                   | +                  | -                       |
| <b>Biochemical tests</b> |                     |                          |                        |                     |                    |                         |
| Catalase test            | +                   | -                        | +                      | -                   | +                  | +                       |
| Coagulase test           | -                   | -                        | -                      | -                   | -                  | -                       |
| H <sub>2</sub> S test    | -                   | -                        | -                      | -                   | +                  | -                       |
| Urease test              | -                   | -                        | +                      | -                   | +                  | -                       |
| <b>Sugar</b>             |                     |                          |                        |                     |                    |                         |
| <b>fermentation</b>      |                     |                          |                        |                     |                    |                         |
| Citrate utilization      | +                   | -                        | +                      | -                   | -                  | -                       |
| Sucrose                  | A                   | A                        | -                      | A                   | AG                 | AG                      |
| Glucose                  | A                   | AG                       | -                      | AG                  | AG                 | AG                      |
| Lactose                  | A                   | A                        | -                      | A                   | -                  | AG                      |
| Maltose                  | A                   | A                        | -                      | A                   | -                  | AG                      |
| Fructose                 | A                   | A                        | -                      | A                   | -                  | AG                      |
| Mannitol                 | A                   | A                        | -                      | A                   | -                  | AG                      |
| <b>Probable identity</b> | <i>Bacillus</i> sp. | <i>Streptococcus</i> sp. | <i>Pseudomonas</i> sp. | <i>Serratia</i> sp. | <i>Proteus</i> sp. | <i>Enterobacter</i> sp. |

Key : (+) = Positive, (-) = Negative, ( FA) = Facultative anaerobes, (AE) = Aerobic, (A) = Acid production, (AG) = Acid and Gas production.

**Table 10: Cultural and microscopic morphology of predominant fungi isolated from soil samples amended with *Chromolaena odorata***

| Surface texture               | Morphology on plates                                     | Under surface colour (Reverse side) | Microscopic features                                                                                                                                                                                                                                                                                               | Probable identity              |
|-------------------------------|----------------------------------------------------------|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Colony strands no sporulating | Whitish colony initially turned yellowish brown with age | Creamy white                        | Non- septate filament, Sporangia and sporangiopores were brown and were located at the tip of unbranched sporangiosphores. They were round with flattened base. Apophysis was absent and collumellae were hemispherical. Sporangiospores were unicellular , round in shape, hyaline to brown and smooth in texture | <i>Rhizopus stolonifer</i>     |
| Powdery (Sporulating)         | Blackish brown with yellow mycelium at the top           | Creamy yellow                       | Globose headed, splitting with age. Long Stipe, smooth brownish in colour. Vesicle globose, thick walled, brownish. Long closely packed metulae. Short but thick phialide, ampulliform and brownish. Globose conidia, rough, black in colour                                                                       | <i>Aspergillus niger</i>       |
| Powdery (Sporulating)         | Dark green                                               | Creamy yellow                       | Short and smooth stipe. Phiallides ampulliform, collumellae very short both divergent and appressed branches. Conidia were smooth, greenish and ellipsoidal in shape                                                                                                                                               | <i>Penicillium chrysogenum</i> |
| Powdery (Sporulating)         | Yellowish green, becoming green with age                 | creamy yellow                       | Radiating head, becoming loosely columnar with age. Stipe is very long varicose and hyaline. Vesicle is dome-shaped. Presence of small metullae. Phiallids is small and ampulliform. Conidia were globose, rough and yellowish green.                                                                              | <i>Aspergillus flavus</i>      |

The major fungi isolated from soil samples amended with *C. odorata* were *Rhizopus stolonifer*, *Apergillus niger*, and *A. flavus* (Table 10). However, *Penicillium chrysogenum* was either completely absent in the soil or its population was too low to be captured during microbial load determination before soil amendment. It was however isolated two weeks after the soil was amended with *C. odorata*.

The presence of all these micro organisms (except *Streptococcus* and *Serratia* species) two weeks after soil amendment) suggests that *C. odorata* stimulated the growing population of some of these beneficial bacteria and fungi or condition for their metabolism was provided by *C. odorata*.

#### **4.2.2 Response of soil microflora to soil amendment with *Chromolaena odorata***

The peak in community population for both bacteria and fungi occurred 4 WAS and 6 WAS respectively after application of *C. odorata* (Table 11) indicating the more competitive nature of bacteria for fast development on freshly incorporated amendment material. This is in agreement with the commonly accepted believe that differences in physiology and metabolic capacities between bacteria and fungi may confer an advantage to bacteria over fungi during the early stages of decomposition especially when the C: N ratio of the decomposing organic matter is less than 1:20 (Buessing and Gessner, 2006; Gunnarsson, 2008; and Wenjing *et al.*, 2013). Bonanomin, *et al.* (2017) stated that the decomposability of the litter entering the soil is likely to be of major importance in determining the major sequential stimulation of bacteria and fungi during the early phase of decomposition.

**Table 11: Population counts of varying groups of microbes in soils amended with *C. odorata***

| Sampling period<br>(WAA) | TVC<br>(cfu/ml)<br>( $\times 10^7$ ) | TCC<br>(cfu/ml)<br>( $\times 10^7$ ) | FCC<br>(cfu/ml)<br>( $\times 10^7$ ) | FC<br>(cfu/ml)<br>( $\times 10^3$ ) | pH   |
|--------------------------|--------------------------------------|--------------------------------------|--------------------------------------|-------------------------------------|------|
| 0                        | 2.2                                  | 1.5                                  | 0                                    | 1.1                                 | 7.07 |
| 2                        | 2.7                                  | 2.0                                  | 0                                    | 1.4                                 | 6.99 |
| 4                        | 2.4                                  | 1.8                                  | 0                                    | 1.5                                 | 6.94 |
| 6                        | 1.8                                  | 1.3                                  | 0                                    | 1.2                                 | 6.87 |
| 8                        | 1.5                                  | 1.0                                  | 0                                    | 1.3                                 | 6.91 |

**Key:** TVC = Total viable counts. TCC = Coliform counts. FCC = Faecal coliform counts. FC = Fungal counts. WAA = Weeks after amendment.

Fungi dominated the latter stages of *C. odorata* decomposition. This could be attributed to the fact that they are known to be better equipped than bacteria for decomposing recalcitrant organic C compounds (Sridhar and Barlocher, 2000; Sarah, *et al.*, 2012; Dilly *et al.*, 2018).

A slight decrease in soil pH was observed as the mineralization of *C. odorata* progressed, though the change in value was too small to suggest negative effect on microbial population.

The increased microbial population upon amendment with *C. odorata* suggests that *C. odorata* is a suitable substrate for microbial growth and activities in the soil. Many plant nutrient elements bound in the Soil Organic Matter are made available to crops by activities of soil microbes. The more the microbial transformations, the better the soil health developed.

Increase in biological activities also improves soil aggregation through the secretion of soil binding mucilages and hyphal growth, improved aggregation in turn increases water infiltration and the ease of plant penetration. Soil biological activities were considered as integral attribute of a healthy soil (Nuria *et al.*, 2012).

#### **4.2.3 Microbial Succession in decomposing *Chromolaena odorata***

Before soil amendment (0 WAA) diverse bacteria and fungal species occurred in the soil. At two weeks after soil amendment (2 WAA) proliferation of microbial flora was observed (Table 12). By four weeks after amendment (4 WAA), a number of microbial species were no longer present. As decomposition progressed bacterial species particularly disappeared while more fungal species came up.

**Table 12: Microbial succession in soils amended with *C. odorata***

| <b>Bacteria species</b>        | <b>0WAA</b> | <b>2WAA</b> | <b>4WAA</b> | <b>6WAA</b> | <b>8WAA</b> |
|--------------------------------|-------------|-------------|-------------|-------------|-------------|
| <i>Bacillus</i> sp.            | +           | +           | +           | +           | +           |
| <i>Streptococcus</i> sp.       | +           | -           | -           | -           | -           |
| <i>Pseudomonas</i> sp.         | +           | +           | +           | -           | +           |
| <i>Serratia</i> sp.            | +           | -           | -           | -           | -           |
| <i>Proteus</i> sp.             | +           | +           | -           | -           | -           |
| <i>Enterobacter</i> sp.        | +           | +           | -           | -           | -           |
| <b>Fungal species</b>          |             |             |             |             |             |
| <i>Rhizopus stolonifer</i>     | +           | +           | -           | -           | +           |
| <i>Aspergillus niger</i>       | +           | +           | +           | -           | +           |
| <i>Penicillium chrysogenum</i> | -           | +           | +           | +           | -           |
| <i>Aspergillus flavus</i>      | +           | +           | -           | -           | +           |

**Key:** WAA = Weeks after soil amendment was applied

(+) = Positive (Present), (-) = Negative (Absent)

By 8 WAA, the population of pathogenic bacteria species such as *Streptococcus*, *Serratia*, *Proteus* and *Enterobacter* species decreased while the population of saprophytic organisms such as *A. niger*, *P. chrysogenum* *Bacillus* and *Pseudomonas* species increased. The production of growth inhibiting substances by soil these organisms such as *Bacillus*, *Pseudomonas* and *Penicillium* may be responsible for the reduction in members of the pathogenic microflora.

The stimulated populations were probably able to compete for food better than the reduced populations. In previous studies, *Bacillus*, *Pseudomonas* and *Aspergillus* species were recognized for their involvement in the decomposition of organic matter as well as for their impact on soil health. They are also known to produce antibiotics (Lartey, 2006).

*Bacillus* spp. are reported to rapidly spread and colonize the root system, enhance the plant growth and yield by direct and indirect Plant Growth Promoting (PGP) activities and control a wide range of plant pathogenic organisms such as *Erwinia carotovora*, *Rhizoctonia solani*, *Macrophomina phaseolina*, *Phytophthora*, *Pythium* species, a number of *Fusarium verticilloides*, *F. moniliforme* etc (Bacon *et al.* 2001; Cavaglieri *et al.* 2005; Kumar *et al.*, 2012). *Bacillus* secretes a number of metabolites that have broad-spectrum of antagonistic activities including antibiotics, siderophores, enzymes chitinase and  $\beta$ -1, 3-glucanase (Ongena and Jacques 2005; Arrebola *et al.*, 2010). These plant beneficial microorganisms exhibit their antagonistic effect on plant pathogens through competition for niches, through parasitism, that may involve production of hydrolytic enzymes such as protease, cellulolase, chitinase,  $\beta$ -1,3 glucanase that destroy pathogen cell walls, protect plants by producing various types

of antifungal compounds and inhibit the pathogens by secreting anti-pathogens metabolites that are capable of systemic acquired resistance in host plants (Compant *et al.*, 2005; Chandrashekara *et al.*, 2012). Some *Bacillus* and *Enterobacter* species are however free –living bacteria capable of nitrogen fixation (Dubey and Maheshwari, 2013

*Pseudomonas* induces suppressiveness in soil as they produce iron-acquiring compounds called Siderophores which have high Fe- binding contents thereby inhibiting the growth of pathogens by limiting their access to soluble ferric iron (Chaube, 2006; Nguyen, 2015).

*Penicillium* was not encountered in the soil samples analyzed before introduction of soil amendment. The appearance of *Penicillium* species two weeks after *C. odorata* incorporation therefore suggests that the amendment stimulated its population in the microbial community. *Penicillium* species are very common soil borne saprophytic fungi and are known to be potential antagonists of pathogenic *Fusarium* (Kasim *et al.*, 2012).

The disappearance of some pathogenic microbial isolates such as *Streptococcus*, *Proteus* and *Enterobacter* species and persistence of *Bacillus* and *Pseudomonas* species as well as *Penicillium* and *Aspergillus niger* within the second and fourth weeks of amendment incorporation may also indicate possibility of suppressiveness of soil amended with *C. odorata* probably as a result of cytotoxicity of leaf leachate of decomposing *C. odorata*. Nandi and Mandal (20010) affirmed that leaf leachate of *C. odorata* can successfully reduced the population of some soil borne plant pathogens and therefore improve suppressiveness of the soil. A soil is considered suppressive

when large numbers of different microorganisms compete with pathogens to reduce their population or in spite of favourable conditions for disease, a pathogen either cannot become established and even if it establishes, produces no disease or establishes and produces disease condition for a short time and then declines (Kumar *et al.*, 2012).

Generally, soil suppressiveness occurs when large numbers of different microorganisms compete for food or niche with pathogens to reduce their population. As decomposition progresses the availability of easily degraded carbon source progressively diminishes thereby creating microbial static conditions that may produce an increase in suppressiveness by favouring competitive saprophytes that are antagonistic to the pathogens (Sarah *et al.*, 2012). Some microbial species are known to induce suppressiveness. *Bacillus*, *Pseudomonas* and *Penicillium* species encountered in this study were among the soil microbes reported to be capable of inducing suppressiveness (Lazarovits, 2001).

#### **4.3.0 Field Experiment**

The soil texture was loamy sand and slightly acidic (pH 6.66) (Table 13). Soil fertility was generally low with Soil Organic Matter (7.78 g/kg), total N (1.78 g/kg), available P (6.23 mg/kg), exchangeable Ca (1.39 cmol/kg), Mg ((0.33 cmol/kg), K (0.15 cmol/kg), and ECEC (2.30 cmol/kg). Also clay content (surface fine fraction) was low (72 g/kg), structural stability index was 5.48% which was less than 9% minimum required. Most of these plant nutrients were below the level preferred for crop production in the Southern Guinea Savannah agro ecological zone of Nigeria.

Federal Ministry of Agriculture and Natural Resources (1990) reported that 20 g/kg, 1.5 g/kg, 8.5 mg/kg, 1.5 cmol/kg, 0.28 cmol/kg, 0.16 cmol/kg and less than 10 cmol/kg as critical levels for Soil Organic Matter, total N, available P, exchangeable Ca, Mg, K, and CEC respectively in this zone. This means that these critical levels must be exceeded before any appreciable yield could be achieved in this agro-ecological zone of Nigeria.

The low soil fertility level recorded for the experimental site may be attributed to coarse textured nature of the soil (% clay content less than 10 and organic matter less than 20 g/kg). This implies that crop on the field will respond to soil amendment application and that more quantity of amendment would be expected to be applied before appreciable yield could be achieved. The low clay content and poor Soil Organic Matter contents suggest a loss of exchangeable bases as a result of erosion and leaching. Low ECEC would result in poor water and nutrients retention and low buffering capacity (Olufemi and Solomon, 2008).

**Table 13: Physico- Chemical Properties of surface soil of experimental site before application of soil amendments in 2014**

| <b>Soil Physical Properties</b>     | <b>Value</b> |
|-------------------------------------|--------------|
| Sand (g/kg)                         | 858          |
| Silt (g/kg)                         | 70           |
| Clay (g/kg)                         | 72           |
| Textural Class                      | Loamy sand   |
| Bulk density (g /cm <sup>3</sup> )  | 1.39         |
| Porosity (%)                        | 47.55        |
| Structural Stability (%)            | 5.48         |
| Water Filled Pore Space (%)         | 15.00        |
| <b>Soil Chemical Properties</b>     | <b>Value</b> |
| Soil pH (Soil:H <sub>2</sub> O w/v) | 6.66         |
| Organic Carbon (g/kg)               | 7.78         |
| Total Nitrogen (g/kg)               | 1.78         |
| Available Phosphorus (mg/kg)        | 6.23         |
| Calcium (cmol/kg)                   | 1.39         |
| Magnesium (cmol/kg)                 | 0.33         |
| Potassium (cmol/kg)                 | 0.15         |
| Sodium (cmol/kg)                    | 0.22         |
| Exchangeable acidity (cmol/kg)      | 0.21         |
| ECEC (cmol/kg)                      | 2.30         |

Low structural stability index is a general characteristic of sandy soil in tropical Southern Guinea Savannah soil. Most soils in this zone are known for their weak or poor structures, poor water retention, high permeability, and vulnerable to surface compaction with adverse consequence of high resistance to root development and penetration (Osunbitan *et al.*, 2005).

Greg (2010) stated that soil physical properties like soil texture, bulk density, porosity, water holding capacity, soil strength, mobility of water into or through the soil and the ease of root penetration are all affected by Soil Organic Matter content. This implies that any soil management practice that increases Soil Organic Matter will reduce soil bulk density, improve soil structure, aeration, water holding capacity all of which are attributes of productive soil (Olabode *et al.*, 2007).

#### **4.3.2 Effect of Soil amendments on plant height of three maize varieties**

DMR-LSR maize was significantly taller than Oba 98 and Oba super 2 from 2 to 10 WAS in the two cropping seasons except at 6 WAS where there was no significant difference ( $p \leq 0.05$ ) between DMR- LSR and Oba 98 in 2014 (Table 14). No significant difference was observed between Oba 98 and Oba supper 2 in the two seasons (except at 6 WAS in 2014) in terms of plant height (Tables 14 and 15). The relatively short height recorded for Oba 98 and Oba super 2 may be due to their genetic make up as most of the Premier seeds are known to develop into short plants.

All the amendments significantly improved maize growth compared to control as from 4 WAS to 10 WAS in 2014 and 2015 growing seasons except *C. odorata* (10 t/ha) at 4 WAS which was not significantly different from that of control in 2014. Plots that were amended with 15t/ha of *C. odorata* + NPK (60:30:15 kg/ha) had significantly

**: Effect of varieties and soil amendment on maize plant height in 2014**

| <b>Varieties</b>                                         | <b>Mean Plant Height (cm)</b> |             |             |             |              |
|----------------------------------------------------------|-------------------------------|-------------|-------------|-------------|--------------|
|                                                          | <b>2WAS</b>                   | <b>4WAS</b> | <b>6WAS</b> | <b>8WAS</b> | <b>10WAS</b> |
| DMR-LSR                                                  | 27.83a                        | 55.94a      | 79.17a      | 128.00a     | 161.94a      |
| Oba 98                                                   | 25.28b                        | 44.61b      | 69.94ab     | 111.11b     | 141.33b      |
| Oba Super 2                                              | 25.06b                        | 43.39b      | 66.11c      | 109.22b     | 140.56b      |
| SE                                                       | 0.62                          | 1.30        | 1.85        | 2.01        | 2.45         |
| <b>Soil amendments</b>                                   |                               |             |             |             |              |
| <i>Chromolaena odorata</i> 10 t/ha                       | 25.56a                        | 42.33bc     | 65.11bc     | 110.22c     | 153.89a      |
| <i>Chromolaena odorata</i> 15 t/ha                       | 25.00a                        | 45.44b      | 71.33b      | 125.67b     | 157.11a      |
| Mineral Fertilizer NPK (120:60:30 kg/ha)                 | 22.11b                        | 39.88bc     | 58.00cd     | 110.78c     | 152.33a      |
| <i>Chromolaena odorata</i> 10t/ha + NPK (60:30:15 kg/ha) | 25.67a                        | 61.44a      | 89.78a      | 133.56ab    | 159.44a      |
| <i>Chromolaena odorata</i> 15t/ha + NPK (60:30:15 kg/ha) | 26.56a                        | 62.88a      | 93.89a      | 141.56a     | 163.56a      |
| No amendment (Control)                                   | 23.44b                        | 35.88c      | 52.33d      | 74.89d      | 101.33b      |
| SE                                                       | 0.87                          | 1.43        | 2.63        | 2.85        | 3.47         |

Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 15: Effect of varieties and soil amendment on maize plant height in 2015**

| Varieties                                                | Mean Plant Height (cm) |         |        |         |          |
|----------------------------------------------------------|------------------------|---------|--------|---------|----------|
|                                                          | 2WAS                   | 4WAS    | 6WAS   | 8WAS    | 10WAS    |
| DMR-LSR                                                  | 29.39a                 | 54.11a  | 80.17a | 130.78a | 164.00a  |
| Oba 98                                                   | 27.67b                 | 46.61b  | 72.33b | 115.06b | 143.33b  |
| Oba Super 2                                              | 26.67b                 | 45.50b  | 69.50b | 113.94b | 142.50b  |
| SE                                                       | 0.50                   | 1.00    | 1.73   | 1.92    | 2.46     |
| <b>Soil amendments</b>                                   |                        |         |        |         |          |
| <i>Chromolaena odorata</i> 10t/ha                        | 27.44b                 | 44.00bc | 68.11b | 113.44d | 155.89b  |
| <i>Chromolaena odorata</i> 15t/ha                        | 27.56b                 | 46.67b  | 72.44b | 129.11c | 160.22ab |
| Mineral Fertilizer NPK (120:60:30 kg/ha)                 | 25.11c                 | 43.44bc | 65.89b | 111.89d | 152.33b  |
| <i>Chromolaena odorata</i> 10t/ha + NPK (60:30:15 kg/ha) | 30.56a                 | 58.67a  | 89.78b | 138.00b | 162.33ab |
| <i>Chromolaena odorata</i> 15t/ha + NPK (60:30:15 kg/ha) | 32.22a                 | 58.67a  | 93.89a | 150.33a | 167.56a  |
| Control (No amendment)                                   | 24.56c                 | 41.00d  | 53.89c | 76.78e  | 101.33c  |
| SE                                                       | 0.70                   | 1.84    | 2.45   | 2.71    | 3.48     |

Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

taller maize height from 4WAS to 8WAS in the two cropping seasons (2014 and 2015).

This result implies that soil amendment was responsible for the high growth rate recorded. The relatively low growth rate observed in the plots containing no amendment and at 2 WAS (Table 14) could be attributed to inherent low Soil Organic Matter, high bulk density, low total porosity and poor soil aeration which are generally associated with poor roots development which is capable of hampering increase in plant height (Adesodun *et al.*, 2015)

#### **4.3.3 Effect of soil amendment on mean number of leaves of maize**

There was no significant difference between the mean number of maize leaves ( $p \leq 0.05$ ) produced by DMR-LSR and Oba 98 at 2 WAS in 2014 and 2015 cropping seasons (Tables 16 and 17). DMR-LSR variety had significantly highest number of leaves as from 4 WAS until 8 WAS in 2014 cropping season and from 4 WAS till 10 WAS in 2015. Oba 98 and Super 2 were not significantly different in terms of number of leaves throughout the 2014 and 2015 cropping seasons.

Treatment with combination of *C. odorata* at 10 t/ha and 15t/ha + NPK (60: 30:15 kg/ha) of mineral fertilizer gave significantly higher mean number of leaves per plant from 6 to 10 WAS in 2014 and 4 to 10 WAS in 2015 cropping seasons.

Significantly high number of leaves recorded in plots with the combination of organic and inorganic amendments may be due to more efficient use of the amendments

**Table 16: Effect of varieties and soil amendments on mean number of maize leaves per plant in 2014**

| Varieties                                                    | Mean number of maize leaves per plant |        |        |        |         |
|--------------------------------------------------------------|---------------------------------------|--------|--------|--------|---------|
|                                                              | 2WAS                                  | 4WAS   | 6WAS   | 8WAS   | 10WAS   |
| DMR-LSR                                                      | 5.39a                                 | 7.33a  | 9.17a  | 12.11a | 12.89   |
| Oba 98                                                       | 5.06ab                                | 6.61b  | 8.28b  | 10.29b | 12.22   |
| Oba Super 2                                                  | 4.94b                                 | 6.56b  | 8.06b  | 10.22b | 12.17   |
| SE                                                           | 0.07                                  | 0.15   | 0.17   | 0.22   | 0.18    |
| <b>Soil amendments</b>                                       |                                       |        |        |        |         |
| <i>Chromolaena odorata</i> 10 t/ha                           | 5.44a                                 | 7.00bc | 8.44bc | 10.44b | 12.00bc |
| <i>Chromolaena odorata</i> 15 t/ha                           | 4.89b                                 | 5.89d  | 7.78c  | 10.44b | 12.33b  |
| Mineral Fertilizer NPK (120: 60:30 kg/ha)                    | 4.89b                                 | 6.33cd | 8.11c  | 10.22b | 11.44c  |
| <i>Chromolaena odorata</i> 10 t/ha + NPK<br>(60:30:15 kg/ha) | 5.22ab                                | 8.00a  | 9.78a  | 12.67a | 14.00a  |
| <i>Chromolaena odorata</i> 15t/ha + NPK<br>(60:30:15 kg/ha)  | 5.55a                                 | 7.67ab | 9.33ab | 11.89a | 13.44a  |
| Control (No amendment)                                       | 4.78b                                 | 6.11d  | 7.55c  | 9.55b  | 11.33c  |
| SE                                                           | 0.07                                  | 0.16   | 0.17   | 0.22   | 0.18    |

Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 17: Effect of varieties and soil amendments on mean number of maize leaves per plant in 2015**

| <b>Mean number of maize leaves per plant</b>              |             |             |             |             |              |
|-----------------------------------------------------------|-------------|-------------|-------------|-------------|--------------|
| <b>Varieties</b>                                          | <b>2WAS</b> | <b>4WAS</b> | <b>6WAS</b> | <b>8WAS</b> | <b>10WAS</b> |
| DMR-LSR                                                   | 5.61a       | 7.78a       | 9.44a       | 12.05a      | 12.78a       |
| Oba 98                                                    | 5.44ab      | 6.78b       | 8.33b       | 11.38b      | 11.50b       |
| Oba Super 2                                               | 5.00b       | 6.56b       | 8.33b       | 10.33b      | 11.22b       |
| SE                                                        | 0.10        | 0.17        | 0.17        | 0.22        | 0.18         |
| <b>Soil amendments</b>                                    |             |             |             |             |              |
| <i>Chromolaena odorata</i> 10 t/ha                        | 5.55b       | 7.55a       | 8.55bc      | 10.56cd     | 12.00bc      |
| <i>Chromolaena odorata</i> 15 t/ha                        | 5.33b       | 6.33b       | 8.00c       | 10.77bc     | 12.33b       |
| Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 5.22b       | 6.22b       | 8.44bc      | 10.22cd     | 11.44cd      |
| <i>Chromolaena odorata</i> 10t/ha + NPK (60:30:15 kg/ha)  | 5.67ab      | 8.11a       | 10.00a      | 12.77a      | 13.55a       |
| <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 6.00a       | 7.88a       | 9.11ab      | 11.89ab     | 14.11a       |
| Control (No amendment)                                    | 5.55b       | 6.11b       | 7.77c       | 9.33d       | 11.11d       |
| SE                                                        | 0.70        | 0.10        | 0.17        | 0.22        | 0.18         |

.Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

offered when mineral and organic fertilizer were combined for crop production. While mineral fertilizer likely supplied immediate needs of plant nutrient elements, organic amendment might improve chemical and physical properties of soil and subsequent release of nutrients to improve yield both in terms of quality and quantity.

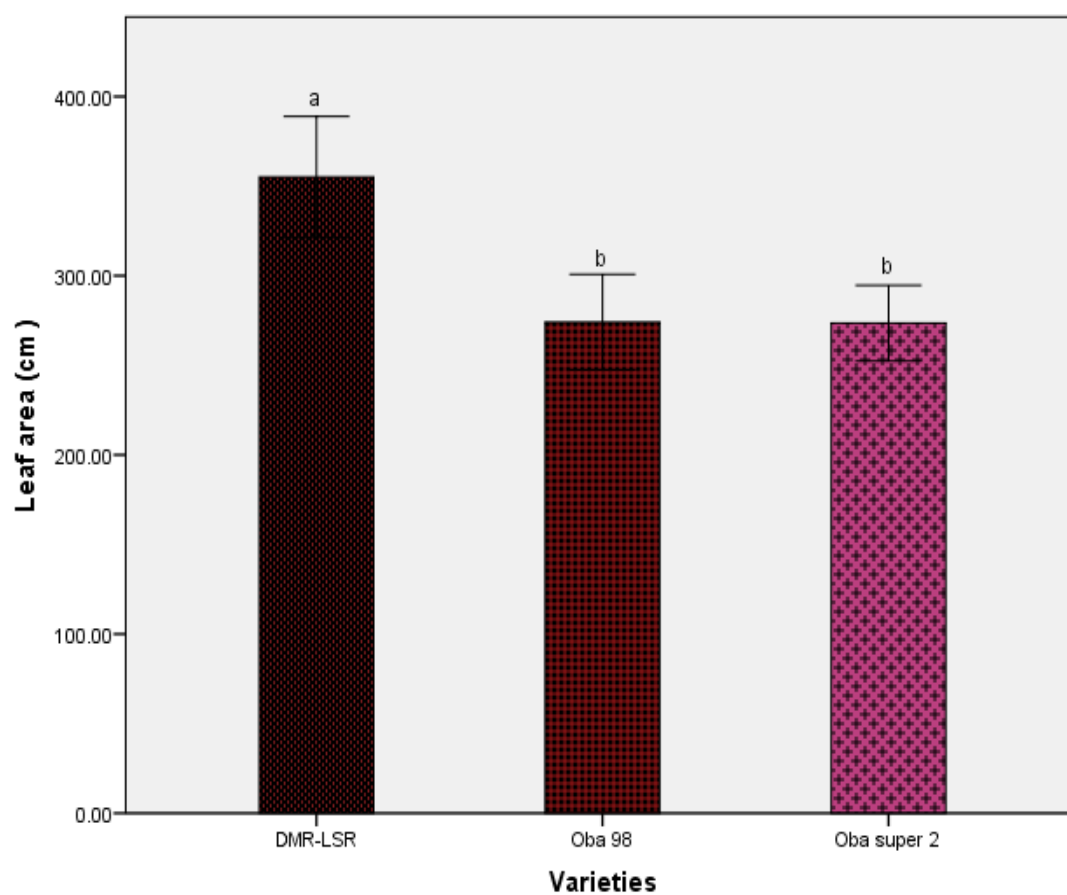
#### **4.3.4 Effect of varieties on leaf area (LA)**

The maize variety DMR-LSR had significantly ( $p \leq 0.05$ ) higher mean leaf area compared to other two varieties (Figures 2 and 3). The two hybrids (Oba 98 and Oba super 2) were not significantly different in terms of leaf area recorded. The higher mean leaf area recorded for DMR-LSR (355.04 cm<sup>2</sup> in 2014 and 356.76 cm<sup>2</sup> in 2015) suggests better accumulation of photosynthetic materials compared with other two varieties. This may invariably result to significantly higher yield output (Olaniyan, 2015). A general increase in leaf area in 2015 season compared to 2014 season was also observed for the three varieties. This is probably as a result of improved fertility status of the soil in 2015 from two years cumulative mineralization of the organic amendment.

#### **4.3.5 Effect of soil amendments on leaf area in 2014 and 2015**

Soil amendment significantly ( $p \leq 0.05$ ) influenced maize leaf area (Figures 4 and 5). *Chromolaena odorata* at 10 t/ha or 15 t/ha combined with 50% mineral fertilizer gave a significantly higher leaf area of maize followed by other amended plots while control plots had significantly lower leaf area in both 2014 and 2015 cropping seasons.

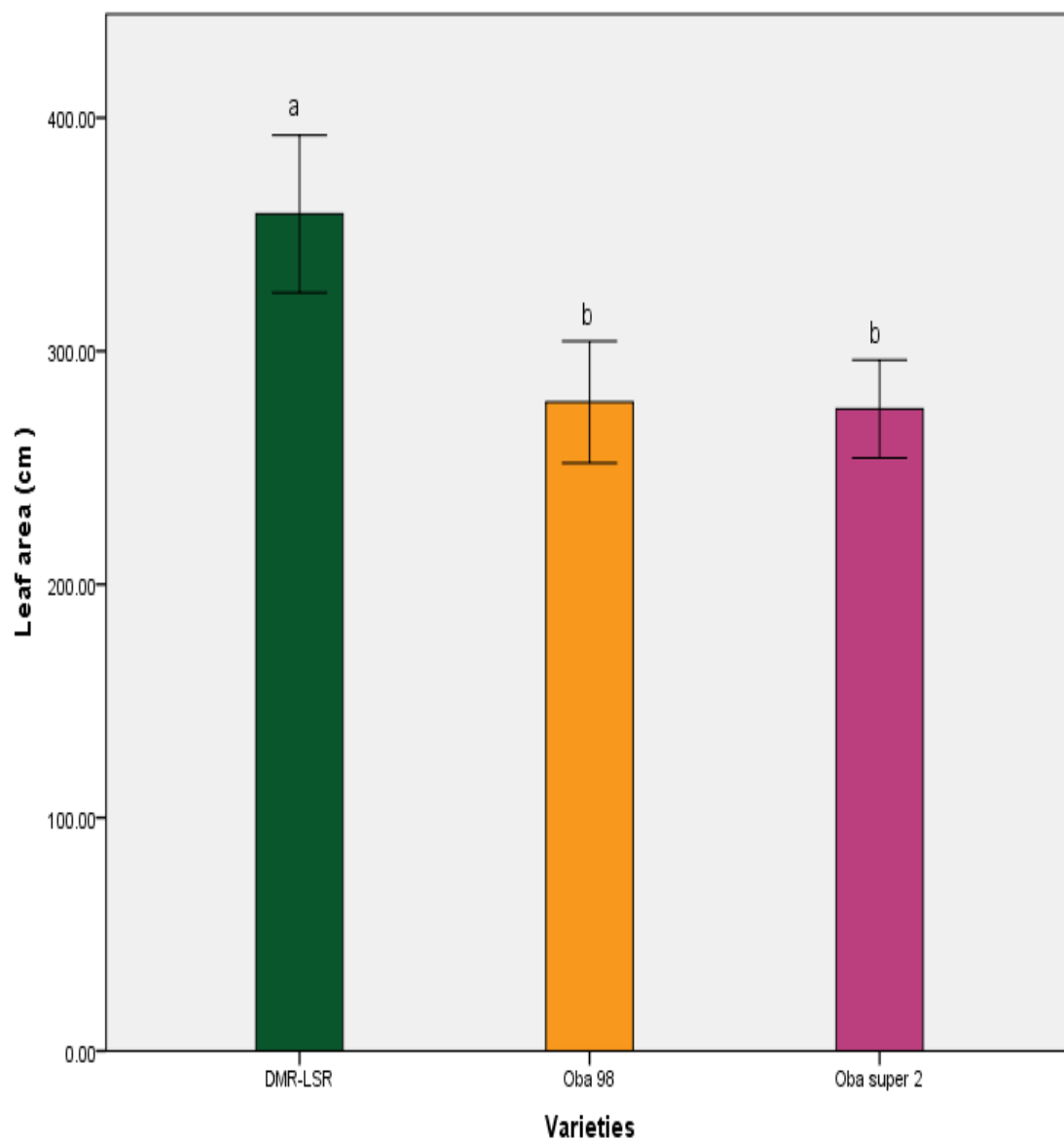
The general increase in leaf area in 2015 growing season over that of 2014 except the control plots attests to the gradual improvement in soil quality and productivity and



**Figure 2: Effect of different maize varieties on leaf area in 2014**

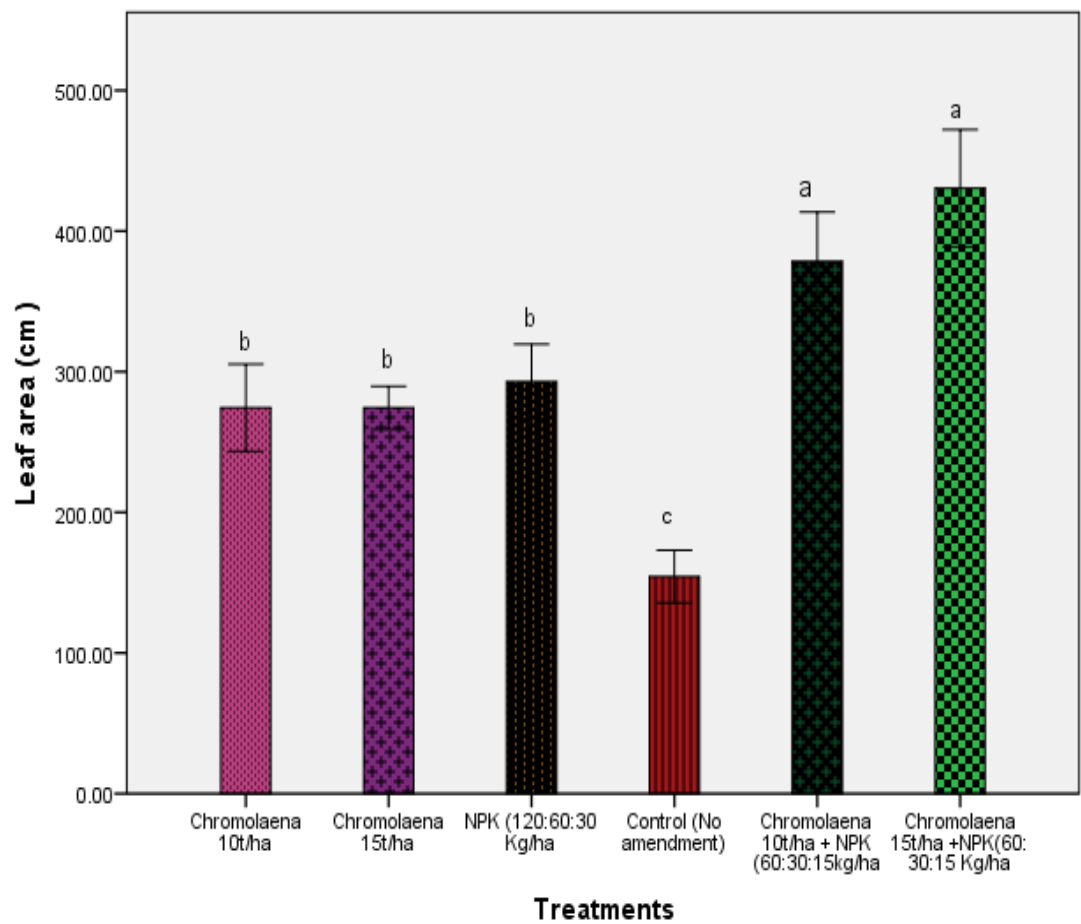
Bars with data labels end with the same letter are not significantly different by NDMRT at ( $P \leq 0.05$ )

Error bars:  $\pm 1$  SE



**Figure 3: Effect of different maize varieties on leaf area in 2015**  
Bars with data labels end with the same letter are not significantly different by NDMRT at  $P \leq 0.05$

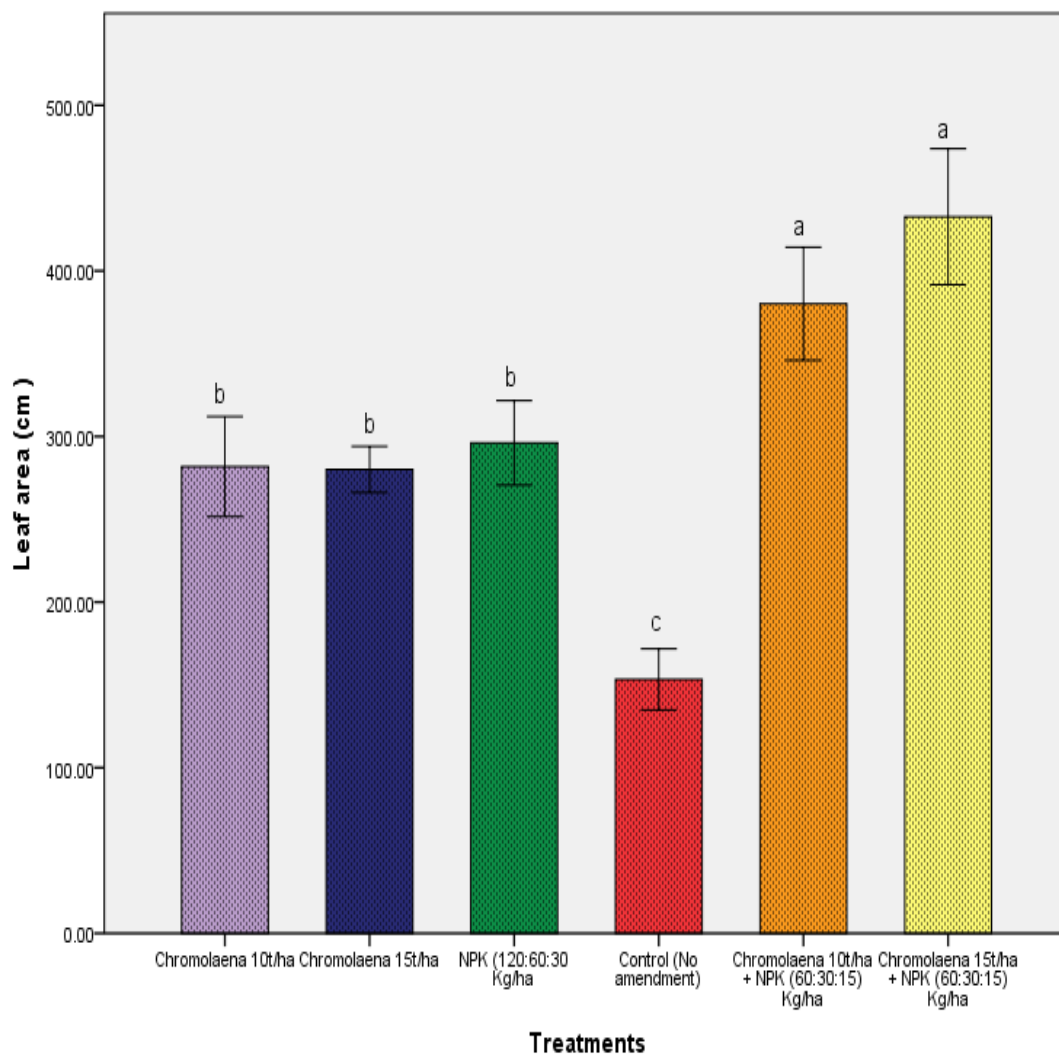
Error bars  $\pm 1$  SE



**Figure 4: Effect of soil amendments on maize leaf area in 2014**

Bars with data labels end with the same letter are not significantly different by NDMRT at  $\leq 0.05$

Error bars +/- 1 SE



**Figure 5: Effect of soil amendments on maize leaf area in 2015**

Bars with data labels end with the same letter are not significantly different by NDMRT at  $P \leq 0.05$

Error bars:  $\pm 1$  SE

better maize yield may be expected. This is because mean leaf area is directly related to the crop yield (Olaniyan, 2015).

#### **4.3.6 Effect of soil amendment on soil physical properties of the experimental site after harvest in 2014 and 2015 cropping seasons**

Soil amendments significantly ( $p \leq 0.05$ ) improved soil moisture, soil bulk density and total porosity (Table 18) in the two cropping seasons. The plots amended with *C. odorata* at 15t/ha singly or in combination with 50% reduced mineral fertilizer level significantly improved soil moisture contents both in 2014 and 2015 compared to control plots and plots with 10 t/ha *C. odorata* rate of application as well as in soil before amendment application in 2014.

Similarly, treatment with *C. odorata* at 15 t/ha applied alone or in combination of 50% recommended dosage of mineral fertilizer gave the least bulk density which are significantly lower than those of control and 100% recommended dosage of mineral fertilizer. A similar pattern of result was observed in soil porosity, bulk density being inversely related to soil porosity.

However, percentage water filled pore spaces (WFPS) were generally low (far less than 50% of total pore spaces) in all the plots. This is an indication of poor water retention and low Soil Organic Matter content (SOM) (Weinhold *et al.*, 2008). All the same, % WFPS of amended plots were significantly higher than the soil before the treatment application. The plots in which 15 t/ha of *C. odorata* was combined with mineral fertilizer gave the best % WFPS. Generally low soil structural stability index

**Table 18: Effect of soil amendments on soil physical properties after harvest in 2014 and 2015**

| Soil Physical Properties                                     | Soil moisture content<br>(g/kg) |         | Bulk density<br>(g/cm <sup>3</sup> ) |        | Total porosity<br>(%) |         | WFPS<br>(%) | Structural<br>stability<br>index (%) |
|--------------------------------------------------------------|---------------------------------|---------|--------------------------------------|--------|-----------------------|---------|-------------|--------------------------------------|
|                                                              | 2014                            | 2015    | 2014                                 | 2015   | 2014                  | 2015    | 2015        | 2015                                 |
| Before amendment application                                 |                                 | 51.30d  |                                      | 1.39cd |                       | 47.55b  | 15.00c      | 5.48a                                |
| <b>Soil Treatments</b>                                       |                                 |         |                                      |        |                       |         |             |                                      |
| <i>Chromolaena odorata</i> 10 t/ha                           | 58.82b                          | 65.30b  | 1.39bc                               | 1.41cd | 47.55bc               | 46.67bc | 19.74ab     | 5.21ab                               |
| <i>Chromolaena odorata</i> 15 t/ha                           | 70.87a                          | 69.00ab | 1.34a                                | 1.38bc | 49.43a                | 47.92b  | 19.86ab     | 4.29ab                               |
| Mineral Fertilizer NPK (120:60:30<br>kg/ha)                  | 64.58ab                         | 65.30b  | 1.42c                                | 1.42de | 46.44c                | 46.42bc | 20.57a      | 4.69ab                               |
| <i>Chromolaena odorata</i> 10t/ha + NPK<br>(60:30:15kg/ha)   | 64.84ab                         | 70.20ab | 1.37ab                               | 1.35ab | 48.30ab               | 49.06a  | 20.15ab     | 4.33ab                               |
| <i>Chromolaena odorata</i> 15 t/ha + NPK<br>(60:30:15 kg/ha) | 70.86a                          | 76.40a  | 1.35a                                | 1.34ab | 49.06a                | 49.43a  | 20.68a      | 5.06ab                               |
| Control (No amendment)                                       | 57.33bc                         | 58.30c  | 1.42c                                | 1.45e  | 46.41c                | 45.23c  | 18.51b      | 2.82c                                |
| SE                                                           | 0.42                            | 1.90    | 0.01                                 | 0.01   | 0.52                  | 0.29    | 0.47        | 0.02                                 |

Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**WFPS** : Water filled pore space

was recorded in all the treatments plot (less than recommended 9%) with the lowest recorded at the control (2.82%) plots indicating high risk of structural degradation due to insufficient organic carbon (Reynolds *et al.*, 2007).

Although no significant improvement was observed in the soil structure as indicated by the structural stability index of the plots amended with *C. odorata* singly or in combination with mineral fertilizer when compared to the value recorded before soil amendment in 2014, the results were still better than the values recorded on control plots.

The low values of soil moisture contents recorded on the experimental field after first and second harvests may be attributed to loamy sand texture of the soil. Sandy soils are known for poor water retention property (Bruad and Lesturgez, 2013). The improvement recorded in soil physical properties such as soil bulk density, soil structure, total pore spaces, water filled pore space, water retention and maintenance of structural stability may be attributed to external organic input in 2014 and 2015 cropping seasons. This is a signal to the potential of this soil improvement strategy not only to sustain crop production but also to increase soil quality overtime. Results in this study agree with assertion of Olabode *et al.* (2007) that increase in SOM improves soil structure, soil aeration, water holding capacity and reduce soil bulk density all of which are attributes of a productive soil.

#### **4.3.7 Effect of soil amendments on soil chemical properties of the experimental site after 2014 and 2015 cropping seasons**

Soil pH generally decreased in all the treatments and control plots compared to pH before the experiment (Table 19a). This was more pronounced in plots with mineral fertilizer alone and control plots (pH values of 5.72 and 5.70 respectively in 2014). Similar result was obtained in 2015 with pH value of 5.77 and 5.87 for plots amended with mineral fertilizer alone and control plots respectively. Soil pH of organically amended plots ranged from 6.03 to 6.47 in 2014 and from 6.23 to 6.30 in 2015

Plots amended with *C. odorata* combined with mineral fertilizer gave the highest significant ( $p \leq 0.05$ ) level of SOM after harvest particularly after 2015 growing season compared to control and mineral fertilizer plots alone both of which had the least Soil Organic Matter contents after 2014 growing season. Total nitrogen (N) also followed similar pattern with *C. odorata* incorporated alone or in combination with mineral fertilizer giving the significantly high total N content with mineral fertilizer alone and control plot having the least.

There was not much variation in available Phosphorus (P) content of the treatment plots. Though plots with 15 t/ha *C. odorata* alone and in combination with mineral fertilizer gave significantly higher level of available P. This was followed by plot with *C. odorata* at 10t/ha alone and in combination with mineral fertilizer as well as mineral fertilizer alone at the rate of NPK (120:60:30 kg/ha). Control plot had the least level of available P. The low value of P recorded in control may be attributed to no addition of input either from mineral fertilizer or organic amendment.

**Table 19a: Effect of soil amendments on soil chemical properties after 2014 and 2015 harvests**

| Soil Physical Properties                                    | Soil pH<br>(1: 2 w/v) |       | Soil organic<br>carbon (g/kg) |                   | Soil organic<br>matter (g/kg) |        | Total Nitrogen<br>(g/kg) |        | Available<br>Phosphorus<br>(mg/kg) |        |
|-------------------------------------------------------------|-----------------------|-------|-------------------------------|-------------------|-------------------------------|--------|--------------------------|--------|------------------------------------|--------|
|                                                             | 2014                  | 2015  | 2014                          | 2015              | 2014                          | 2015   | 2014                     | 2015   | 2014                               | 2015   |
| Before soil amendment application                           |                       | 6.66a |                               | 4.51bc            |                               | 7.77bc |                          | 1.78de |                                    | 6.23bc |
| <i>Chromolaena odorata</i> 10 t/ha                          | 6.03c                 | 6.27b | 4.01c                         | 4.29c             | 6.90ab                        | 7.40c  | 1.55c                    | 1.92cd | 6.21b                              | 6.13c  |
| <i>Chromolaena odorata</i> 15 t/ha                          | 6.10c                 | 6.30b | 4.32abc                       | 4.69ab            | 7.44a                         | 8.09ab | 1.68c                    | 2.01c  | 8.79a                              | 6.15c  |
| Mineral Fertilizer NPK (120:60:30<br>kg/ha)                 | 5.72d                 | 5.77c | 3.34d                         | 3.37d             | 5.75bc                        | 5.81d  | 1.26d                    | 1.76e  | 6.51b                              | 5.84c  |
| <i>Chromolaena odorata</i> 10t/ha + NPK<br>(60:30:15) kg/ha | 6.37b                 | 6.30b | 4.13bc                        | 4.93a             | 7.69a                         | 8.49a  | 2.02b                    | 2.18b  | 6.68b                              | 6.75b  |
| <i>Chromolaena odorata</i> 15t/ha + NPK<br>(60:30:15 kg/ha) | 6.47ab                | 6.23b | 4.53a                         | 5.06a             | 7.40a                         | 8.72a  | 2.45a                    | 2.59a  | 8.79a                              | 8.01a  |
| Control (No amendment )                                     | 5.70d                 | 5.87c | 3.12d                         | 2.80 <sup>e</sup> | 4.67c                         | 4.82e  | 1.11d                    | 0.91f  | 4.61c                              | 4.38d  |
| SE                                                          | 0.07                  | 0.07  | 0.12                          | 0.18              | 0.27                          | 0.31   | 0.1                      | 0.11   | 0.33                               | 0.23   |

Means followed by the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

The relatively high SOM, total N and available P on the plots with amendment materials, as revealed in Table 19a, was likely from nutrient elements released from the amendment materials. After intake of crops, the nutrients left over in the soil were still relatively abundant. This invariably increases their contents in the soil after harvest. The N content values obtained from all amended plots was above critical level 1.5 g/kg or 0.15 % reported by Olufemi and Solomon (2008) and was therefore within the medium value. The result was different in control plots with the N content of 1.11g/kg and 0.91 g/kg in 2014 and 2015 respectively.

The plots amended with 15 ton/ha *C. odorata* alone gave a significantly ( $p \leq 0.05$ ) higher value of exchangeable Ca (1.80 cmol/kg) content after the first harvest in 2014 (Table 19b) than other treatments while plots amended with combination 15 t/ha *C. odorata* + %50 dose of mineral fertilizer had significantly higher values in 2015 (2.55 cmol/kg). The control plots and preamended soils had the least values of Ca.

Significantly high ( $p \leq 0.05$ ) value of magnesium (Mg) content was also recorded in the plots with 15t/ha and 10t/ha of *C. odorata* applied alone or in combination of mineral fertilizer in 2014 but it was *C. odorata* at 15t/ha applied alone that gave the highest value in 2015 (0.56 cmol/kg). Control plots recorded the least of Mg value 0.33 cmol/kg in 2014 and 0.31 cmol/kg in 2015).

There was no much variation in potassium (K) content among the soils in treatment plots in both growing seasons. However, plots that received organic input had significantly high value of K than those with mineral fertilizer alone and control plots. Similarly, effective cation exchange capacity (ECEC) also showed a similar trend

**Table 19b: Effect of soil amendments on soil chemical properties (exchangeable bases and ECEC) after 2014 and 2015 harvests**

| Soil Chemical Properties                                  | Ca        |       | Mg     |        | K       |       | Na     |        | EA    |       | ECEC   |        |
|-----------------------------------------------------------|-----------|-------|--------|--------|---------|-------|--------|--------|-------|-------|--------|--------|
|                                                           | (cmol/kg) |       |        |        |         |       |        |        |       |       |        |        |
| Soil amendments                                           | 2014      | 2015  | 2014   | 2015   | 2014    | 2015  | 2014   | 2015   | 2014  | 2015  | 2014   | 2015   |
| Before soil amendment application                         |           | 1.39d |        | 0.33c  |         | 0.15c |        | 0.22b  |       | 0.21d |        | 2.30e  |
| <i>Chromolaena odorata</i> 10 t/ha                        | 1.40c     | 1.77c | 0.38ab | 0.52ab | 0.120b  | 0.24b | 0.23ab | 0.22b  | 0.61d | 0.61c | 2.73c  | 3.36c  |
| <i>Chromolaena odorata</i> 15 t/ha                        | 1.80a     | 1.97c | 0.41a  | 0.56a  | 0.123a  | 0.28a | 0.20c  | 0.24ab | 0.60d | 0.60c | 3.10a  | 3.65bc |
| Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 0.95d     | 1.40d | 0.35bc | 0.34c  | 0.120b  | 0.16c | 0.25a  | 0.24ab | 0.70b | 0.65b | 2.36d  | 2.78d  |
| <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 1.40c     | 2.13b | 0.40a  | 0.49b  | 0.127ab | 0.24b | 0.23ab | 0.23ab | 0.80a | 0.71a | 2.96b  | 3.80b  |
| <i>Chromolaena odorata</i> 15 t/ha+ NPK (60:30:15 kg/ha)  | 1.60b     | 2.55a | 0.40a  | 0.50b  | 0.130a  | 0.28a | 0.20c  | 0.24ab | 0.65c | 0.66b | 3.00ab | 4.24a  |
| Control (No amendment)                                    | 1.00d     | 1.13d | 0.30d  | 0.31c  | 0.090c  | 0.16c | 0.23ab | 0.21b  | 0.66c | 0.66b | 2.28d  | 2.46e  |
| SE                                                        | 0.07      | 0.11  | 0.01   | 0.02   | 0.004   | 0.02  | 0.004  | 0.01   | 0.04  | 0.04  | 0.08   | 0.15   |

Means followed by the same letter (s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**EA:** Exchangeable acidity    **ECEC:** Effective cation exchange capacity

with plots amended with *C. odorata* at 15 t/ha + mineral fertilizer recording a significantly

( $p \leq 0.05$ ) high ECEC than those of mineral fertilizer alone and control in 2015 (4.24 cmol/kg)). This result indicates that organic input significantly improved basic cations in the soil with subsequent increase in ECEC. Though, the improvement was not very high yet result showed the potential of the *C. odorata* as the quality organic source that could be used to improve soil fertility for sustainable crop production in this climatic zone when used repeatedly on the farm.

It should be noted that part of the nutrient would have been removed by the harvested maize crop. For instance Prasad (1997) estimated that a maize crop that produces 5-6t/ha would have removed 100-150kg nitrogen and 40-60kg  $P_2O_5$  from the soil by harvest. Similarly, Fakorede (2001) stated that 20kg of nitrogen is removed from soil for every tons of maize harvested. Maize, being regarded as an aggressive feeder (Uphoof, 2002) would have removed substantial nutrient added to the soil by these amendment materials. Generally, the gradual increase in most chemical properties such as soil organic carbon, total nitrogen, available phosphorus, exchangeable bases and effective cation exchange capacity observed after 2014 and 2015 growing seasons over that before amendment application also implies that this soil improvement strategy is capable of sustaining crop productivity in Southern Guinea Savannah climatic zone of Nigeria.

#### **4.3.8 Correlation of some soil chemical properties after harvest of maize crops**

Soil organic carbon was found to have positive strong correlation with soil exchangeable bases as well as with total N and available P with coefficient of

correlation (r) ranging from 0.65- 0.93 in 2014 (Table 20) and 0.55 to 0.77 in 2015 (Table 21). This suggests that soil amended with *C. odorata* would invariably increase levels of other plant nutrients in this site.

#### **4.4.1 Effect of Soil amendments on yield of maize plants in the two growing seasons**

DMR-LSR performed significantly better than Oba 98 and Oba super 2 in terms of cob weight and weight of 1000 seeds as well as cob weight per plot and biological yield. Variety had no effect on number of cobs per plot and grain yield per hectare in the two growing seasons. However, maize varieties had significant influence on the Cob weight per plot and weight of 1000 seeds in the two growing seasons. Cob weight per plot and biological yield were not significantly influenced by maize varieties in 2015 harvest (Tables 22a and 22b).

Generally, all treatments significantly improved maize yield as compared to control plots. Plots that received combination of amendment materials performed significantly better than other treatments in most yield parameters such as number of cobs per plot, grain weight per cob, cobs weight per plot, grain yield per hectare and biological yield per hectare in the two growing seasons (Table 22a and 22b). This finding corroborates those of Hussaini *et al.* (2001), Mani (2004), Namakka *et al.* (2009) and Sharifai *et al.* (2012) that combination of inorganic and organic amendments gave better yield results than sole applications of either. Treatment had no effect on weight of 1000 seeds in first harvest but did in the second harvest in 2015.

**Table 20: Correlation of some soil chemical Properties after first year harvest in 2014**

|                            | Soil pH | SOC    | SOM    | Total N | Available P | Ca     | Mg     | K      | ECEC |
|----------------------------|---------|--------|--------|---------|-------------|--------|--------|--------|------|
| <b>Soil pH</b>             | -       |        |        |         |             |        |        |        |      |
| <b>Soil organic carbon</b> | 0.89**  | -      |        |         |             |        |        |        |      |
| <b>Soil organic matter</b> | 0.77**  | 0.84** | -      |         |             |        |        |        |      |
| <b>Total Nitrogen</b>      | 0.87**  | 0.85** | 0.70** | -       |             |        |        |        |      |
| <b>Available P</b>         | 0.54*   | 0.65** | 0.73** | 0.45    | -           |        |        |        |      |
| <b>Ca</b>                  | 0.71**  | 0.89** | 0.68** | 0.63**  | 0.63**      | -      |        |        |      |
| <b>Mg</b>                  | 0.65**  | 0.75** | 0.65*  | 0.69**  | 0.66**      | 0.64** | -      |        |      |
| <b>K</b>                   | 0.51*   | 0.69** | 0.60** | 0.46    | 0.76**      | 0.63** | 0.72*  | -      |      |
| <b>Effective CEC</b>       | 0.82**  | 0.93** | 0.78** | 0.75**  | 0.75**      | 0.96** | 0.84** | 0.73** | -    |

\*\* Correlation highly significant at 0.01 level (2-tailed)

\* Correlation significant at 0.05 level (2-tailed)

**Table 21: Correlation of some soil chemical Properties after second year harvest in 2015**

|                             | Soil pH | SOC    | SOM    | Total N | Available P | Ca     | Mg     | K      | ECEC |
|-----------------------------|---------|--------|--------|---------|-------------|--------|--------|--------|------|
| <b>Soil pH</b>              | -       |        |        |         |             |        |        |        |      |
| <b>Soil organic Carbon</b>  | 0.77**  | -      |        |         |             |        |        |        |      |
| <b>Soil organic matter</b>  | 0.77**  | 1.00** | -      |         |             |        |        |        |      |
| <b>Total Nitrogen</b>       | 0.55*   | 0.89** | 0.89** | -       |             |        |        |        |      |
| <b>Available Phosphorus</b> | 0.57*   | 0.83** | 0.83** | 0.94**  | -           |        |        |        |      |
| <b>Exchangeable Ca</b>      | 0.64**  | 0.88** | 0.88** | 0.89**  | 0.88**      | -      |        |        |      |
| <b>Exchangeable Mg</b>      | 0.76**  | 0.86** | 0.86** | 0.71**  | 0.62**      | 0.72** | -      |        |      |
| <b>Echangeable K</b>        | 0.70**  | 0.82** | 0.82** | 0.74**  | 0.67**      | 0.86** | 0.83** | -      |      |
| <b>Effective CEC</b>        | 0.69**  | 0.92** | 0.92** | 0.89**  | 0.87**      | 0.99** | 0.79** | 0.89** | -    |

\*\* Correlation highly significant at 0.01 level (2-tailed)

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

**Table 22a: Main effects of varieties and soil amendments on yield of maize plants in 2014 and 2015**

| Treatments                                            | Number of<br>cobs/plot |        | Grain wt. /cob<br>(g) |         | Weight of 1000 seeds<br>(g) |          |
|-------------------------------------------------------|------------------------|--------|-----------------------|---------|-----------------------------|----------|
|                                                       | 2014                   | 2015   | 2014                  | 2015    | 2014                        | 2015     |
| <b>Maize varieties</b>                                |                        |        |                       |         |                             |          |
| DMR-SR                                                | 60.67                  | 57.94  | 84.70a                | 85.27a  | 278.91a                     | 278.41a  |
| Oba 98                                                | 59.83                  | 54.33  | 77.03ab               | 87.28ab | 249.90b                     | 244.17b  |
| Oba Super 2                                           | 59.72                  | 58.88  | 71.93b                | 77.64b  | 228.97c                     | 233.03b  |
| SE                                                    | 1.76                   | 2.04   | 3.13                  | 2.37    | 7.19                        | 4.88     |
| <b>soil amendments</b>                                |                        |        |                       |         |                             |          |
| <i>Chromolaena odorata</i> (10 t/ha)                  | 38.00c                 | 40.22c | 68.17b                | 84.32b  | 252.29                      | 240.28b  |
| <i>Chromolaena odorata</i> (15 t/ha)                  | 39.44c                 | 44.33c | 73.55b                | 90.78ab | 255.52                      | 248.05ab |
| Mineral Fertilizer NPK (120:60:30<br>kg/ha)           | 83.89ab                | 66.11b | 88.18a                | 89.84ab | 257.38                      | 250.71ab |
| <i>Chromolaena</i> (10t/ha) + NPK (60:30:15<br>kg/ha) | 79.89b                 | 73.89b | 94.81a                | 95.10a  | 262.97                      | 262.59a  |
| <i>Chromolaena</i> (15t/ha) + NPK (60:30:15<br>kg/ha) | 91.00a                 | 92.67a | 98.64a                | 99.93a  | 248.57                      | 268.04a  |
| Control (No amendment)                                | 28.22d                 | 25.11d | 43.98c                | 40.39c  | 238.83                      | 241.01b  |
| SE                                                    | 2.48                   | 2.88   | 4.43                  | 3.35    | 10.16                       | 6.90     |

Means with the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 22 b:** Main effects of varieties and soil amendments on Yield of Maize plants in 2014 and 2015

| Maize varieties                                    | Cob Weight<br>(kg/plot) |        | Grain Yield<br>(t/ha) |       | Biological Yield (t/ha) |        |
|----------------------------------------------------|-------------------------|--------|-----------------------|-------|-------------------------|--------|
|                                                    | 2014                    | 2015   | 2014                  | 2015  | 2014                    | 2015   |
| DMR-SR                                             | 6.97a                   | 6.01   | 2.75                  | 2.63  | 5.41a                   | 6.00   |
| Oba 98                                             | 6.81a                   | 5.86   | 2.48                  | 2.53  | 5.22ab                  | 5.59   |
| Oba Super 2                                        | 5.93b                   | 5.81   | 2.33                  | 2.51  | 4.64b                   | 5.60   |
| SE                                                 | 0.25                    | 0.28   | 3.14                  | 0.13  | 0.17                    | 0.28   |
| <b>Soil amendments</b>                             |                         |        |                       |       |                         |        |
| <i>Chromolaena odorata</i> (10 t/ha)               | 3.20c                   | 3.88c  | 1.27c                 | 1.68c | 2.81c                   | 3.86c  |
| <i>Chromolaena odorata</i> (15 t/ha)               | 3.58c                   | 4.67c  | 1.40c                 | 2.01c | 3.24c                   | 4.26c  |
| Mineral Fertilizer NPK (120:60:30 kg/ha)           | 9.66b                   | 6.89b  | 3.62b                 | 2.98b | 7.08b                   | 6.46b  |
| <i>Chromolaena</i> (10t/ha) + NPK (60:30:15 kg/ha) | 9.83b                   | 7.86b  | 3.65b                 | 4.49a | 7.26b                   | 9.92a  |
| <i>Chromolaena</i> (15t/ha) + NPK (60:30:15 kg/ha) | 11.46a                  | 10.52a | 4.57a                 | 4.67a | 8.38a                   | 10.43a |
| Control (No amendment)                             | 1.69d                   | 1.51d  | 0.60d                 | 0.51d | 1.88d                   | 1.68d  |
| SE                                                 | 0.36                    | 0.28   | 0.21                  | 0.19  | 0.25                    | 0.55   |

Mean figures followed by the same letter(s) along the same column are not significantly different by NDMRT at  $P \leq 0.05$

These results indicated that *C. odorata* at 10t/ha and 15t/ha combined with mineral fertilizer at a reduced rate of 50% of recommended dosage were able to provide soil nutrients in quantity and rate sufficient to increase maize yield. This is probably, due to high nutrient release efficiency of both *C. odorata* and mineral fertilizer combination. According to Agbede *et al.* (2013) and Brian (2014) amendment of soil with organic materials results in improved soil properties and soil function.

The increased grain yield observed with *C. odorata* amendment in this study may thus be due to release of mineralized plant nutrients inherent in the *C. odorata* by soil microbes naturally present in the soil as well as improved soil properties observed in the plots amended with organic materials. Vanlauwe *et al.* (2001) posited that combination of organic amendment and mineral fertilizer produced better crop yield as a result of efficiency use of nutrients supply by mineral fertilizer and better soil physical properties enhanced by organic amendment.

There was general decrease in most yield components in plots amended with sole application of mineral fertilizer between 2014 and 2015 harvests whereas in plots where organic amendment was applied at 15 t/ha in combination with 50% mineral fertilizer, slight increase in yield components such as number of cobs/plot, grain weight/cob, weight of 1000 seeds (g), grain yield t/ha and biological yield t/ha were recorded (Tables 22a and 22b). This implies that application of *C. odorata* at 15 t/ha in combination with 50% mineral fertilizer as a system of soil quality improvement is sustainable since a system is said to be sustainable over a defined period if outputs do not decrease when inputs are not increased (Monteith 1990; Hansen 1996; Smith and MacDonald 1998; Jules 2008; Sarah *et al.*, 2015).

#### **4.4.2 Interaction effects of varieties and soil treatments on number of cobs/plot in 2014**

Table 23 showed that soil treatments contributed more to the number of cobs per plot recorded than varieties. However, NPK (120: 60: 30 kg/ha) gave significantly highest number of cobs per plot (95.33) in DMR-LSR plots as against 79.67 and 76.67 in Oba 98 and Oba super 2 plots respectively. In general, soil treatment combination of 15t/ha plus NPK (60:30:15 kg/ha) mineral fertilizer produced significantly highest number of maize cobs per plot in all the three varieties. This may be as a result of efficient used of available plant nutrients provided by combination of *C. odorata* (organic source) and mineral fertilizer (inorganic source). There was no interaction between the treatments and varieties in terms of number of cobs per plot in 2015 yield results.

#### **4.4.3 Interaction effects of soil treatments and varieties on weight of maize cobs/plot**

Table 24 shows that soil treatments contributed significantly more to the weight of maize cobs per plot than varieties especially on the plots with application of 10 and 15 t/ha organic amendment alone and on the plots with 15 t/ha of organic amendment in combination with mineral fertilizer as well as in control in 2014 growing season. The result obtained from treatment with mineral fertilizer alone showed that varieties contributed significantly more to the weight of maize cobs/plot. DMR-LSR produced significantly highest maize cobs weight per plot (11.83 kg/plot). However, 15t/ha of organic amendment in combination with mineral fertilizer gave significantly highest maize cobs/plot for the three varieties.

**Table 23: Interaction effect of varieties and soil treatments on number of cobs/plot in 2014**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                          | <b>Number of cobs/plot</b> |
|------------------------|----------------------------------------------------------------|----------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10t/ha                              | 29.33e                     |
|                        | <i>Chromolaena odorata</i> 15t/ha                              | 29.33e                     |
|                        | Mineral Fertilizer NPK (120:60:30) kg/ha                       | 95.33a                     |
|                        | <i>Chromolaena odorata</i> 10t/ha + Fert. NPK (60:30:15) kg/ha | 88.00abc                   |
|                        | <i>Chromolaena odorata</i> 15t/ha + Fert. NPK(60:30:15) kg/ha  | 93.33a                     |
|                        | No amendment (Control)                                         | 28.67e                     |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10t/ha                              | 39.67de                    |
|                        | <i>Chromolaena odorata</i> 15t/ha                              | 28.00e                     |
|                        | Mineral Fertilizer NPK(120:60:30) kg/ha                        | 79.67bc                    |
|                        | <i>Chromolaena odorata</i> 10t/ha + Fert. NPK(60:30:15) kg/ha  | 75.67c                     |
|                        | <i>Chromolaena odorata</i> 15t/ha + Fert. NPK(60:30:15) kg/ha  | 91.00ab                    |
|                        | No amendment (Control)                                         | 28.00e                     |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10t/ha                              | 45.00d                     |
|                        | <i>Chromolaena odorata</i> 15t/ha                              | 44.00d                     |
|                        | Mineral Fertilizer NPK(120:60:30) kg/ha                        | 76.67c                     |
|                        | <i>Chromolaena odorata</i> 10t/ha + Fert. NPK(60:30:15) kg/ha  | 76.00c                     |
|                        | <i>Chromolaena odorata</i> 15t/ha + Fert. NPK(60:30:15) kg/ha  | 88.00abc                   |
|                        | No amendment (Control)                                         | 28.02e                     |
|                        | SE                                                             | 4.30                       |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 24: Interaction effect of varieties and soil treatments on weight of maize cobs/plot in 2014**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                     | <b>weight of maize cobs/plot (kg)</b> |
|------------------------|-----------------------------------------------------------|---------------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 2.35ef                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 3.00ef                                |
|                        | Mineral Fertilizer NPK (120:60:30) kg/ha                  | 11.83a                                |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15) kg/ha | 10.64a                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha +NPK (60:30:15) kg/ha  | 12.25a                                |
|                        | No amendment (Control)                                    | 1.75f                                 |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 3.28ef                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 4.29e                                 |
|                        | Mineral Fertilizer NPK(120:60:30 kg/ha)                   | 9.58bc                                |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 10.66ab                               |
|                        | <i>Chromolaena odorata</i> 15 t/ha +NPK (60:30:15 kg/ha)  | 11.36ab                               |
|                        | No amendment (Control)                                    | 1.73f                                 |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 3.95e                                 |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 3.46ef                                |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 7.50d                                 |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 8.20cd                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 10.81ab                               |
|                        | No amendment (Control)                                    | 1.60f                                 |
|                        | SE                                                        | 4.30                                  |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

Also in 2015 growing season, soil treatment effects prevailed more on the weight of maize cobs per plot than variety effects (Table 25). This is similar to the one obtained in 2014 (Table 24) with the treatment combination of 15 t/ha of *C. odorata* with mineral fertilizer (NPK 60:30:15 kg/ha) producing significantly highest weight of maize cobs/plot.

#### **4.4.4 Interaction effect of soil treatments and varieties on grain wt/cob (g) of maize**

Table 26 shows that varieties DMR-LSR and Oba 98 contributed more to grain weight of the maize cob than soil treatments. This was however not the case in Oba super 2 where soil treatments surpassed the variety effect. It can be seen that mineral fertilizer combined with organic amendment gave the best grain weight/cob. No interaction was observed between soil amendments and varieties in grain weight per cob in 2014.

#### **4.4.5 Interaction effects of soil treatments and varieties on biological yield of maize**

Table 27 indicate that soil treatments contributed more to the biological yield output than variety in 2014. Mineral fertilizer combined with organic amendment produced significantly largest quantity of biological yield of all the varieties as well as single application of mineral fertilizer in DMR-LSR varieties.

Table 28 show a similar trend with Table 27 with soil treatments effect contributing more to biological yield than the varieties effects. Also, amendment of *C. odorata* in combination with mineral fertilizer gave significantly best biological yields of the three varieties.

**Table 25: Interaction effect of varieties and soil treatments on weight of maize cobs/plot in 2015**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                     | <b>weight of maize cobs/plot (kg)</b> |
|------------------------|-----------------------------------------------------------|---------------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 4.21gh                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 4.61efgh                              |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 6.72cdef                              |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 8.76bc                                |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 10.25ab                               |
|                        | No amendment (Control)                                    | 1.50i                                 |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 3.75h                                 |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 5.12efgh                              |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 7.73cd                                |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 7.22cde                               |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 9.82ab                                |
|                        | No amendment (Control)                                    | 1.49i                                 |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 3.69h                                 |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 4.29gh                                |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 6.21defg                              |
|                        | <i>Chromolaena odorata</i> 10t/ha + NPK (60:30:15 kg/ha)  | 7.59cd                                |
|                        | <i>Chromolaena odorata</i> 15t/ha + NPK (60:30:15 kg/ha)  | 11.50a                                |
|                        | No amendment (Control)                                    | 1.55i                                 |
|                        | SE                                                        | 0.43                                  |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 26: Interaction effect of varieties and soil treatments on maize grain weight/ cobs in 2015**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                     | <b>Grain weight/<br/>cobs (g)</b> |
|------------------------|-----------------------------------------------------------|-----------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 91.64abc                          |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 94.44ab                           |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 93.42ab                           |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 91.72abc                          |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 100.21ab                          |
|                        | No amendment (Control)                                    | 40.15e                            |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 91.24abc                          |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 102.74a                           |
|                        | Mineral Fertilizer NPK(120:60:30 kg/ha)                   | 91.95abc                          |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 98.58ab                           |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 96.16ab                           |
|                        | No amendment (Control)                                    | 43.01e                            |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 70.08d                            |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 75.12cd                           |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 84.14bcd                          |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 95.01ab                           |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 103.43a                           |
|                        | No amendment (Control)                                    | 38.02e                            |
|                        | SE                                                        | 3.05                              |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 27: Interaction effect of varieties and soil treatments on maize biological yield in 2014**

| <b>Maize varieties</b> | <b>Soil treatments</b>                                    | <b>Biological yield (t/ha)</b> |
|------------------------|-----------------------------------------------------------|--------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 2.20fg                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 2.85efg                        |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 8.54a                          |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 8.19ab                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 8.81a                          |
|                        | No amendment (Control)                                    | 1.88g                          |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 2.90efg                        |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 3.59e                          |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 6.89bcd                        |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 1.55abc                        |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 8.13ab                         |
|                        | No amendment (Control)                                    | 2.06fg                         |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 3.35ef                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 3.24efg                        |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 6.12d                          |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 6.61cd                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 7.89ab                         |
|                        | No amendment (Control)                                    | 1.90g                          |
|                        | SE                                                        | 0.42                           |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

**Table 28: Interaction effect of varieties and soil treatments on maize biological yield in 2015**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                     | <b>Biological yield (t/ha)</b> |
|------------------------|-----------------------------------------------------------|--------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 4.350ef                        |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 4.28ef                         |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 5.97de                         |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 8.96bc                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 10.66a                         |
|                        | No amendment (Control)                                    | 1.74gh                         |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 3.75fg                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 4.61ef                         |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 7.07cd                         |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 7.02cd                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 9.56ab                         |
|                        | No amendment (Control)                                    | 1.56h                          |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 3.44fgh                        |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 7.65fg                         |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 6.29de                         |
|                        | <i>Chromolaena odorata</i> 10t/ha + NPK(60:30:15) kg/ha   | 7.26cd                         |
|                        | <i>Chromolaena odorata</i> 15 t/ha +NPK (60:30:15 kg/ha)  | 5.54a                          |
|                        | No amendment (Control)                                    | 1.73fg                         |
|                        | SE                                                        | 0.42                           |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

#### **4.4.6 Interaction effects of soil treatments and varieties on 1000 seeds of maize**

Table 29 shows that mineral fertilizer applied singly and in combination with *C. odorata* in DMR-LSR variety gave significantly higher weight of 1000 seeds in 2015. The dominating effect of varieties was also observed in the three varieties. No interaction between treatments and varieties on 1000 seeds weight was observed in 2014.

#### **4.4.7 Effect of soil amendment on maize harvest index**

Varieties had no significant effect on the maize Harvest Index (H. I) in both growing seasons (2014 and 2015). Plots that received soil amendments had significantly higher H. I. than those of control in 2014 (Figure 6).

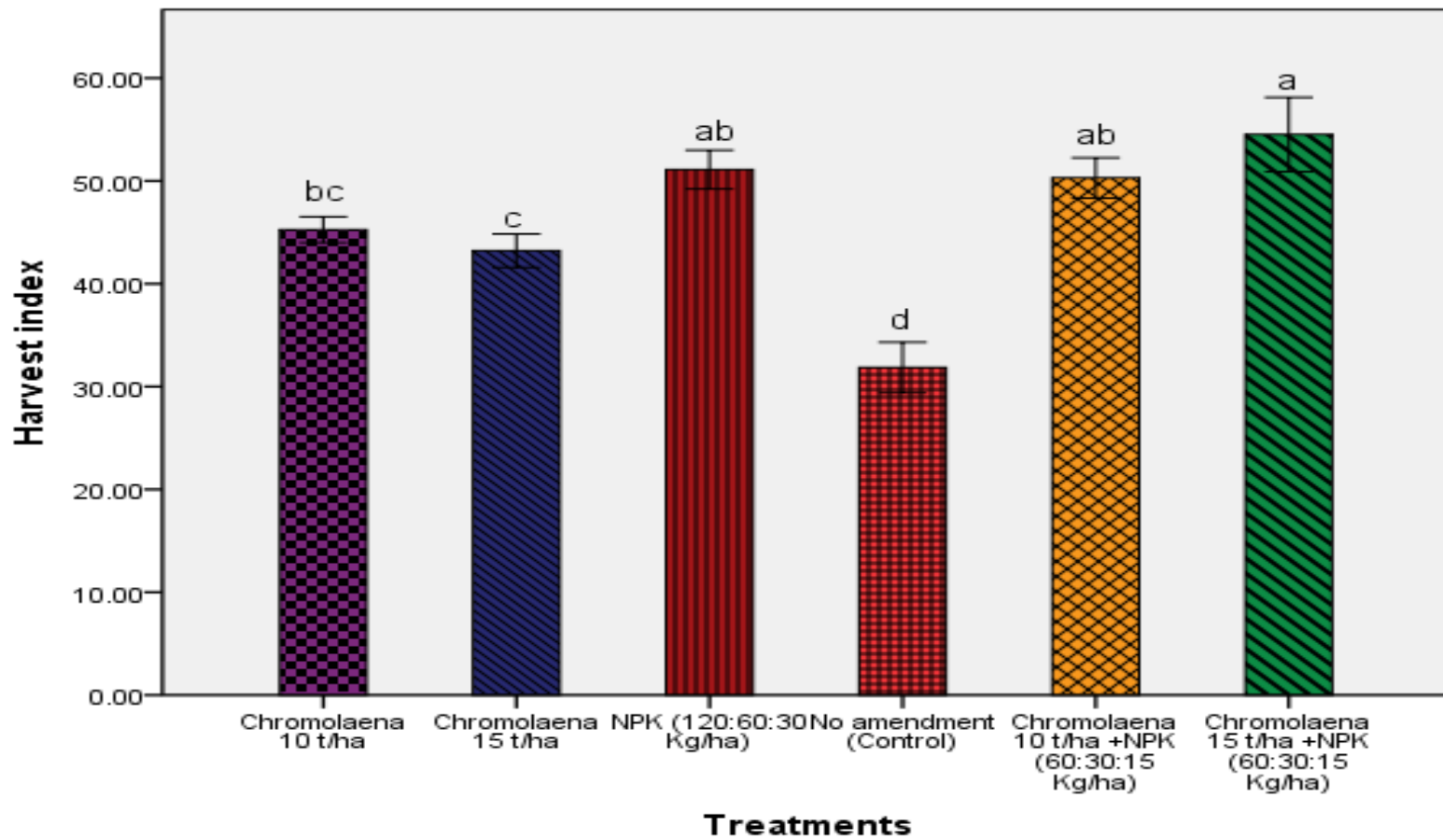
It can also be seen that H.I of plots that received NPK-120:60:30 kg/ha were not significantly different from those plots that received 10 t/ha of *C. odorata* plus 50% recommended dosage of mineral fertilizer and the one that received 15 t/ha *C. odorata* plus 50% recommended dosage of mineral fertilizer. However, Soil amended with *C. odorata* alone at 10 t/ha and 15 t/ha performed significantly lower than other treatments that received amendments in 2014.

In 2015 growing season, all the plots with soil amendment produced significantly high H.I. compared to control plots (Figure 7). However soil amended with *C. odorata* at 15 t/ha + mineral fertilizer produced significantly highest H.I in 2014 and *C. odorata* at 15 t/ha alone in 2015 (47.19).

**Table 29: Interaction effect of varieties and soil treatments on weight of 1000 maize seeds in 2015**

| <b>Maize varieties</b> | <b>Soil treatment</b>                                     | <b>weight of 1000 seeds (g)</b> |
|------------------------|-----------------------------------------------------------|---------------------------------|
| <b>DMR-LSR</b>         | <i>Chromolaena odorata</i> 10 t/ha                        | 254.76bcde                      |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 263.33bcd                       |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 304.73a                         |
|                        | <i>Chromolaena odorata</i> 10t/ha + NPK (60:30:15 kg/ha)  | 282.13ab                        |
|                        | <i>Chromolaena odorata</i> 15t/ha + NPK (60:30:15 kg/ha)  | 301.67a                         |
|                        | No amendment (Control)                                    | 262.20bcd                       |
| <b>Oba 98</b>          | <i>Chromolaena odorata</i> 10 t/ha                        | 235.27cdefg                     |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 267.88bc                        |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 220.27fg                        |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 255.97bcde                      |
|                        | <i>Chromolaena odorata</i> 15t/ha + NPK (60:30:15 kg/ha)  | 251.67bcdef                     |
|                        | No amendment (Control)                                    | 233.97defg                      |
| <b>Oba super 2</b>     | <i>Chromolaena odorata</i> 10 t/ha                        | 230.80defg                      |
|                        | <i>Chromolaena odorata</i> 15 t/ha                        | 212.93g                         |
|                        | Mineral Fertilizer NPK (120:60:30 kg/ha)                  | 227.13efg                       |
|                        | <i>Chromolaena odorata</i> 10 t/ha + NPK (60:30:15 kg/ha) | 249.67cdef                      |
|                        | <i>Chromolaena odorata</i> 15 t/ha + NPK (60:30:15 kg/ha) | 250.80bcdef                     |
|                        | No amendment (Control)                                    | 226.87efg                       |
|                        | SE                                                        | 3.98                            |

Means with the same letter(s) along the column are not significantly different by NDMRT at  $P \leq 0.05$

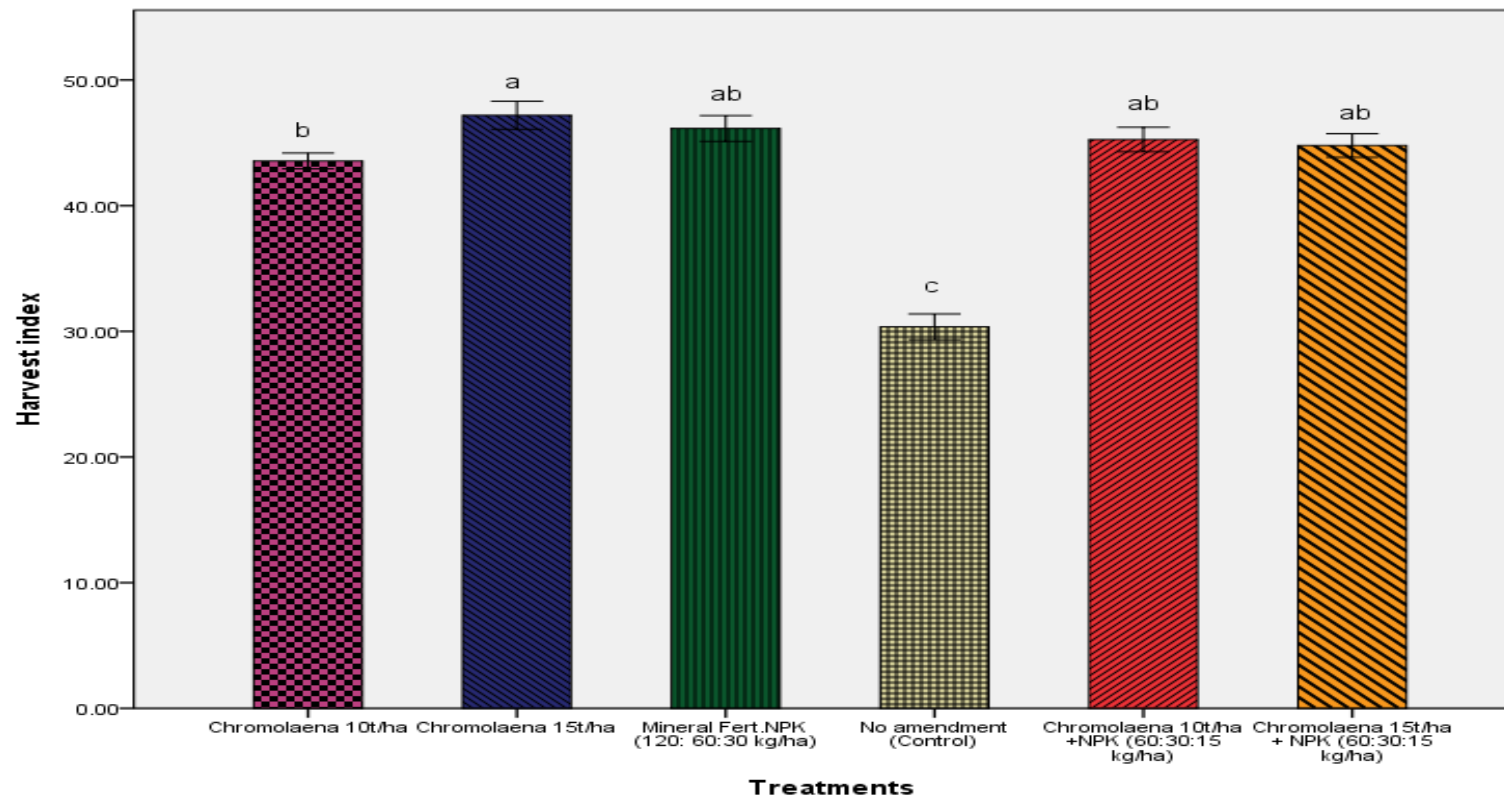


120

**Figure 6:** Effect of soil amendments on maize harvest index

Bars with data label end with the same letter (s) are not significantly different by NDMRT at  $P \leq 0.05$

Error bars:  $\pm 1$  SE



**Figure 7:** Effect of soil amendments on maize harvest index in 2015

Bars with data labels end with the same letter are not significantly different by NDMRT at  $P \leq 0.05$

Error bars  $\pm 1$  SE

#### **4.4.8 Correlation of some yield parameters and leaf area**

Table 30 indicated that most of the yield components measured bore positive strongly correlation with grain yield except 1000 seeds weight which did not significantly correlate with cob number per plot, cob weight per plot, biological yield per plot and grain yield per plot.

Most of the yield components measured in 2015 harvest were also strongly correlated with grain yield except 1000 seeds weight which didn't significantly correlate with harvest index. Their coefficients of correlation range from 0.13 to 0.99 (Table 31).

Most of the yield components measured were strongly correlated with each other and with grain yield in the two years of study, particularly in the second harvest. The implication of this is that any soil improvement strategy that affects any of these yield components may affect all others which may eventually result to grain yield increase.

**Table 30: Correlation of some yield parameters and leaf area of maize grown on amended soil in 2014**

| <b>Parameter</b>       | <b>Cobs Number</b> | <b>Cobs wt<br/>(kg/plot)</b> | <b>Cob grain<br/>Wt (g/cob)</b> | <b>Biological<br/>Yield (t/ha)</b> | <b>Grain<br/>Yield<br/>(t/ha)</b> | <b>1000 seeds<br/>Wt (g)</b> | <b>Harvest Leaf<br/>Index (H.I)</b> | <b>Area</b> |
|------------------------|--------------------|------------------------------|---------------------------------|------------------------------------|-----------------------------------|------------------------------|-------------------------------------|-------------|
| Cobs Number            | -                  |                              |                                 |                                    |                                   |                              |                                     |             |
| Cobs Wt. (kg/plot)     | 0.97**             | -                            |                                 |                                    |                                   |                              |                                     |             |
| Cob grain Wt. (g/cob)  | 0.77**             | 0.80**                       | -                               |                                    |                                   |                              |                                     |             |
| Biol. Yield Wt. (t/ha) | 0.98**             | 0.99**                       | 0.80**                          | -                                  |                                   |                              |                                     |             |
| Grain Yield (t/ha)     | 0.97**             | 0.96**                       | 0.73**                          | 0.96*                              | -                                 |                              |                                     |             |
| 1000 seeds Wt. (g)     | 0.13               | 0.17                         | 0.32*                           | 0.18                               | 0.18                              | -                            |                                     |             |
| Harvest index (H.I)    | 0.71**             | 0.65**                       | 0.62**                          | 0.65**                             | 0.79**                            | 0.13                         | -                                   |             |
| Leaf Area              | 0.60**             | 0.63**                       | 0.61**                          | 0.63**                             | 0.66**                            | 0.27                         | 0.57**                              | -           |

\*\* Correlation highly significant at 0.01 level (2-tailed)

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

**Table 31: Correlation of some yield parameters and leaf Area of the maize grown on amended soil in 2015**

| <b>Parameter</b>        | <b>Cobs Number</b> | <b>Cobs wt (g/plot)</b> | <b>Cob grain Wt (g/cob)</b> | <b>Biological Yield (t/ha)</b> | <b>Grain Yield (t/ha)</b> | <b>1000 seeds wt (g)</b> | <b>Harvest Index (H.I)</b> | <b>Leaf Area</b> |
|-------------------------|--------------------|-------------------------|-----------------------------|--------------------------------|---------------------------|--------------------------|----------------------------|------------------|
| Cobs number             | -                  |                         |                             |                                |                           |                          |                            |                  |
| Cobs Wt. (g/plot)       | 0.97**             | -                       |                             |                                |                           |                          |                            |                  |
| Cob grain Wt. (g/cob)   | 0.66**             | 0.77**                  | -                           |                                |                           |                          |                            |                  |
| Biological Yield (t/ha) | 0.97**             | 0.99**                  | 0.75**                      | -                              |                           |                          |                            |                  |
| Grain yield (t/ha)      | 0.97**             | 0.99**                  | 0.79**                      | 0.99**                         | -                         |                          |                            |                  |
| 1000 seeds Wt. (g)      | 0.28*              | 0.32*                   | 0.32*                       | 0.34*                          | 0.33*                     | -                        |                            |                  |
| Harvest Index (H.I)     | 0.55**             | 0.57**                  | 0.82**                      | 0.52**                         | 0.61**                    | 0.13                     | -                          |                  |
| Leaf area               | 0.78**             | 0.79**                  | 0.67**                      | 0.80**                         | 0.79**                    | 0.42**                   | 0.47**                     | -                |

\*\* Correlation highly significant at 0.01 level (2-tailed)

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

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### Conclusion

Soil amendment with *C. odorata* at rate of application 7.5% w/w significantly ( $p \leq 0.05$ ) lower bulk density and improved mean soil moisture content (SMC), total porosity, and grain yield than other treatments in the potted experiment. The order of their effectiveness in soil quality improvement was *C. odorata* > *Amaranthus spinosus* > *Aspilia africana* in the potted experiment.

Amendment of soil with *C. odorata* increased soil microbial population and diversity. This treatment improved proliferation of saprophytes and suppression of pathogens.

*Chromolaena odorata* at 15 t/ha combined with NPK fertilizer (60:30:15 kg/ha) on the field produced the best improvement in soil properties and crop yield than other treatments at the end of second cropping season.

Application of *C. odorata* enhanced significant positively correlation between soil organic matter and other soil quality indicators measured particularly macronutrients such Ca, Mg, K, total N and available P. Most yield components were also positively correlated with maize grain yield.

*Chromolaena odorata*, therefore, has great potential for use as soil amendment to improve soil quality and maize performance in Southern Guinea Savannah zone of Nigeria especially when 15 t/ha of is combined with NPK (60:30:15 kg/ha).

## **Recommendations**

The relatively seasonal decrease in most yield parameters observed between 2014 and 2015 on plots amended with mineral fertilizer alone suggests that continuous use of this method of soil fertility improvement on this site is not sustainable. Productive use of small amounts of inorganic fertilizer along with organic source nutrients such *C. odorata* has the greatest likelihood of success and therefore recommended.

Soil amendment with *Chromolaena odorata* at 10 t/ha or 15t/ha combined with mineral fertilizer at NPK (60:30:15 kg/ha) is recommended as one of the options to sustainable soil quality improvement in Guinea Savannah zone of Nigeria.

Similar trial is suggested to be undertaken in other Savannah zones of the country to confirm these current findings and also assess the impact of *C. odorata* as soil amendment material on yield performance of other crops.

Research effort is also recommended to derive a technique that will make the collection of the organic input less labourious so as to make the adoption of this cropping system attractive to farmers.

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