UNIVERSITY OF CAPE COAST

AMELIORATING COMPACTION IN A GHANAIAN COASTAL SAVANNA ACRISOL WITH COMPOST

SADATA WUAKU

2021

UNIVERSITY OF CAPE COAST

AMELIORATING COMPACTION IN A GHANAIAN COASTAL SAVANNA ACRISOL WITH COMPOST

BY

SADATA WUAKU

Thesis submitted to the Department of Soil Science of the School of Agriculture, College of Agriculture and Natural Science, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy Degree in Land Use and Environmental Science

AUGUST 2021

DECLARATION

Student's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ……………………………. Date ……………….

Name: ………………………………………………………………………

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature …..…………………….. Date ……………….

Name: ………………………………………………………………………….

ABSTRACT

Soil compaction has deletenous effects on crop production by preventing soil to realize its full productive potentials even if crop residue is applied. The study sought to evaluate the efficiency of using compost to ameliorate soil compaction. A research was carried out during the major and minor season of 2019 at the Teaching and Research Farm of the School of Agriculture University of Cape Coast, in the Central Region of Ghana. The experiments were arranged in a randomized complete Block design (RCBD) with four replications. The four different levels of compaction that were imposed were NTP, 3 mild, moderate and high they were used to assess the effect of compaction on the growth of plant. The different types of compost used were maize compost (MC), cassava compost (CC) and pineapple compost (PC). The composts treatments were the sub-plots whilst the main plots were the various forms of soil compaction imposed. Composts were replicated 4 times in each block. In total, there were 48 sub-plots (4 main blocks × 3 plots × 4 replications). The physical (porosity, bulk density, HC and moisture content) and chemical (pH, CEC, OC, Tot.N and Avai.P) properties of the soil were measured and data collected was subjected to analysis of variance using GenStat Statistical package (12th Edition). Data gathered from the various blocks indicate that regardless of the level of soil compaction, maize compost alleviated soil compaction compared to other composts. In addition, maize compost resulted in the highest grain yield.

KEY WORDS

Amelioration

Compaction in soils

Compost

Maize

ACKNOWLEDGEMENTS

I am grateful to the Lord Almighty God for giving me strength, guidance and life which made it possible for me to carry out this study.

I owe a depth of gratitude and admiration to my supervisor Prof. D. Okae-Anti whose diligence, guidance and counseling has helped to sharpen my intellect for the completion of this work. His dedication will never be forgotten. He was more of a father to me. His criticisms, comments and correction, were all helpful. God is not unjust to forget his labour of love.

I appreciate the contribution and impact of Dr. Kofi Atia, Prof. E.A. Ampofo, Mr. Seth Essien, Rev. and Mrs. Harrison Amponsah and Dr. Daniel Nyadanu whose contribution gave me background information and knowledge that contributed immensely to this work.

Also, to Mr. Bismark Otabil, Mrs. Seraphine Agbeli-Nutsu, Margaret Wuaku and Samson D. Nutsu. I wish to place on record that your contribution to analysis of soil sample is highly appreciated.

DEDICATION

To my children: Gladys Klenam Nutsu, Florence E. Nutsu and Seraphine B. Nutsu and all Sundry who contributed to the completion of this work; I say may Almighty God bless you.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Farming is pivotal activity in the economy, successive governments have tried to ensure maximum productivity in farm produce. Individual farmers have their own style of farming which are subject to change due to government intervention and or research activities. Maize is cultivated in almost all parts of Ghana and the mode of cultivation is subject to change due to the reasons stated above. Composting and its application to ameliorate soil compaction is unusual in Ghana (Edith, 2018). A soil compaction ameliorated with compost will increase the porosity of the soil and also result in low soil bulk density which leads to an increase in crop yield.

Background of the Study

Soil compaction is a process of increasing soil density and reducing porosity, related to the changes to the soil structure and usually an increase in strength and hydraulic conductivity reduction (Atkinson, 2014). Soil compaction increases soil bulk density and soil strength, while enhancing porosity, aggregate stability index, soil hydraulic conductivity and reduces soil health (Shah & Tanveer, 2017). This means compaction creates a poor environment for crop root which limits root growth.

In this modern world, there have been innovative ways of farming which is accessible to tractors, fertilizers and improved seeds to farmers. This is to shift the paradigm of using simple farming tools such as the hoe and the cutlass to increasing use of tractor mounted implements to enhance efficiency in farm operations. This invariably shortens the time needed to cultivate the soil and subsequently solves problems associated with inadequate farm labourers.

Although tractor use improves farm efficiency, improper use can lead to physical degradation of the land, with soil compaction being one of the most serious issues. On wet soils, soil compaction caused by heavy machinery with high tyre inflation pressure occurs most frequently during soil tillage (Reintam *et al*., 2005). It results in reduced soil porosity, high soil bulk density and resistance to root penetration (Czyz *et al*., 2001; Lipiec & Hatano, 2003; Usaborisut & Niyamapa, 2010). These impede germination, seed emergence, root and shoot growth and crop growth (Berisso *et al*., 2012). This affects soil fertility, aeration, hydraulic properties and water and nutrient uptake (Ishag *et al*., 2001). It must be emphasized that soil compaction in agricultural fields may not only be attributed to tractor mounted usage. Grazing animals and anthropogenic activities significantly increase soil compaction which affect the response of plants (Lai & Kumar, 2020).

Physical properties of soil are currently receiving a lot of attention since they may limit the growth and development of crop roots and seedlings. As the use of larger and heavier farm machinery is advocated, the difficulties connected with soil compaction are getting increasingly serious.

To increase the productivity of these areas, soil compaction must be reduced for prolific crop development and production. It's difficult, expensive, and time-consuming to research root tolerance to soil compaction, especially when environmental circumstances aren't controlled.

This method is time-consuming and costly in the field. Controlled laboratory tests, on the other hand, provide a good chance for screening crop genotypes for tolerance to soil compaction (Asady *et al*., 1985). Even though agricultural traffic causes soil compaction, Batey (2009) and Günal *et al.* (2015) observed that soil compaction is not caused by machinery alone but also by animals, raindrop and human traffic.

Whether soil compaction is caused by animal, machinery, raindrop or human traffic, it has a number of negative effects on the soil quality and crop production (Duttman *et al*., 2014). Soil compaction also affects physico-chemical properties of soil. It affects carbon and nitrogen sequestration, increases soil erosion, greenhouse gas emission, eutrophication and cause loss of biodiversity (Lal, 2015).

Many mechanisms have been developed to amend compacted soils because of the danger it poses on soil, crop yield and the environment. McCauley *et al.* (2009) stated that lime, elemental sulphur and gypsum, biosolids, manure and compost are materials that could be used to amend the physico-chemical properties of a problem soil and noted that manure and compost are good amendment for compacted soils. Karagiannis *et al*. (2011) also used cover crops as soil amendment on compacted soil and observed that the cover crops serve as mulch and their deep roots are able to penetrate to amend highly compacted soil to increase maize growth and yield. Mujdeci *et al*. (2017) also used crop residue to amend compacted soil and concluded that using crop residue enhances soil conditions by improving soil water holding capacity and circulation, aeration, penetration resistance and bulk density and this leads to increased plant root growth and crop yield. Kingwell and Fuchsbichler (2011) reported that crop rotation which includes forage, cereal, oil seed and pulse crops that vary in rooting depth and type combined with good agronomic management practices have the tendency to reduce soil compaction issues. Soil compaction could be ameliorated through deep tillage with a disk chisel, subsoiler or ripper, as disk chisel and subsoiler are able to penetrate soil below normal tillage depth and break up compacted layers, temporary "fluffs" and increase water infiltration without inverting the soil (USDA, 2016). Chen *et al*. (2014) also noted that applying peat moss in a 2:1 ratio as soil amendment is able to prevent soil compaction to enhance crop growth in a garden.

Among the various means by which soil compaction could be amended, composts are the best source of soil amendment for compacted soils. The harvest of compost has changed the dynamics and availability of nutrients in the soil (Adler *et al*., 2015). Compost are able to open up compacted soil, bind loose soil particles together and increase the aggregate stability of the soil because of their colloidal property (Coleman *et al*., 2017). Bouajila and Sanaa (2011) stated that soil permeability is improved due to the presence of an appreciable amount of compost. According to them, compost give a better structural stability to the soil. Adding compost to the soil increases total nitrogen and organic carbon depending on the type and the level of amendment applied (Floudas *et al*., 2012). Hence, compost increase the fertility of the soil and its productive capacity. In view of this, this study seeks to assess the effects of maize stalk, stubble, and seed pods on growth and yield of maize at different levels of soil compaction. Tractor and its implements are mostly used in land preparation from medium to large scale maize production in the Cape Coast Municipality. Therefore, information on continuous use of the tractor on the productivity of soils and the use of maize residues to manage compacted soils will be of importance to the development of mechanized agriculture for both medium and large - scale crop production.

Statement of the Problem

Farming evolves from Adam's time to our modern world; this led the researcher to be curious about why farmers in Ajumako Bisease travelled a distance away from their homes in search of a suitable land to farm whilst there are bushy areas around settled places in Ajumako Bisease.

Farmers in five farming communities within Ajumako Enyan Essiam district (Ajumko Bisease, Enyan Abaasa, Breman Essiam, Enyan Denkyira and Mando) were asked about reasons for cultivating in distant farms? Farmers from these selected communities had farms a distance away from home and engage in cocoa as their main crop. From the investigation, it was observed that lands closer to farmers has been abandoned due to soil compaction.

Furthermore, the soil compaction result in high bulk density and low porosity which does not support plant growth. Owing to the low soil nutrient status, crop yields are low in most tropical soil. To replenish the fertility of the soils to improve crop yield, some farmers use synthetic fertilizers. However, the use of inorganic fertilizers has suffered severe drawbacks due to their high costs, highly variable nature of tropical soils and inherent low nutrient conversion efficiency (Steffens, 2008).

It is therefore necessary to find a more suitable approach to help address the situation in order for farmers to make good use of the land available and or closer to them. The use of compost to reduce the adverse impact of soil compaction on the root of plants has to be critically considered (Williams & Weil, 2004).

Problem diagnosis

From the five selected communities in Ajumako Enyan Essiam district, it was observed that about ninety five per cent (95%) of farmers cultivate crops on lands which are far away from home. To rekindle their interest in abandoned lands closer to their homes, farmers were asked if they would farm on abandoned lands at their backyards if something could be done to regain the fertility of the soil? Eighty per cent (80%) of the farmers agreed to do so whilst sixty five per cent (65%) of those who agreed to farm on replenished land expresses their desire to farm in large scale on abandoned lands.

Causes of the problem

Following critical observation of farmers' fields and interviews, the following are some of the possible causes why farmers abandoned land.

- Soil compaction.
- Loss of soil fertility
- No or little knowledge in composting

General Objective

The general objective of this study was to evaluate the efficiency compost in ameliorating compaction.

Specific Objectives

The specific objectives for the study were:

- To determine the effect of soil compaction on soil physical and chemical properties.

- To investigate the efficiencies of different compost type to ameliorate soil compaction.

Research Questions

The above objectives were based on the following research questions:

1. How does soil compaction affect soil physical properties?
2. How efficient are the various soil amendments in ameliorating compaction?
3. In what ways are the growth and biomass yield of maize affected by soil compaction?

Significance of the Study

The significance of this study is to help farmers to ameliorate compacted soils by application of compost in order to amend them for high crop yield. The study will also show that low crop yield may not always be due to lack or poor nutrient supply, but could also be contributed by soil compaction.

The study identified possible ways to improve maize production on compacted soil. This was done by examining the impact of various composts on soil. Maize compost, cassava compost, pineapple compost which was utilized for the research are all from local sources. These helped determine the best compost for high yield in compacted soils at different levels.

Lastly, soils that are abandoned because of their compactness and loss of fertility will be utilized to provide food for the ever-growing population in Ghana. This is to help the peasant farmer with modern methods of improving infertile lands for agriculture.

Delimitations

The study was conducted on the UCC Technology village and all the data gathered were subjected to prevailing conditions on the farm as case study. There are lot of composting material but this study utilized only maize compost, cassava compost and pineapple compost. Moreover, the compaction level was a matter of choice to this study. They are a lot of varieties of crops but it was the decision of the researcher to settle on maize.

Limitations

The conduct of this research was hindered by certain factors. Firstly, financial constraint was one of the major setbacks to this research. Hiring tractor for field preparation was very expensive and a challenge.

Definition of Terms

Bulk density: Bulk density is defined as dry weight of soil per unit volume of soil.

Compost: Compost is organic materials decayed by microbial population in a moist, warm and oxygen present environment (Raabe, 2001).

Porosity: Porosity is defined as a measure of void spaces in a material, and is a fraction of the volume of void over the total volume, between 0 and 1, or as a percentage between 0% and 100% or porosity is the quality of being porous, or full of tiny holes.

Anthropogenic: According to Cambi *et al.* (2015), anthropogenic are causes of human activities as opposed to those occurring in natural environments without human influences.

Amelioration: Amelioration is defined as an act or instance of making better; the state of making something better.

Soil Amelioration: Soil amelioration entails applying soil amendments strategically, such as lime, dolomite, gypsum, organic matter, or clay-rich subsoil, or using deep tillage, or a mix of both.

Soil compaction: Soil compaction is the physical compacting of soil by an applied force that destroys structure, reduces porosity, limits water and air infiltration, increases root resistance, and often results in lower crop yields (Wolkowski & Lowery, 2008).

Agricultural traffic: Agricultural traffic is the compacting of the soil by agricultural machinery which reduces soil fertility.

Soil amendments: Soil amendments are organic or inorganic matter added to the soil to improve texture, water retention, permeability, water infiltration, drainage, aeration, structure and chemical properties of the soil.

Biomass: Biomass is plant or animal materials used for energy product or in various industrial processes as raw material for a range of products.

Ecological: According to Oxford dictionary is the branch of biology that deals with the relations of organisms to one another and to their physical surroundings.

Organization of the Study

This study is made of five chapters:

Chapter One (1) embraces the introduction, the objective of the study – that is the general and the specific objectives, problem statement and justification, research questions, hypotheses, significance of the study and how the chapter was organized. Chapter Two (2) deals with the relevant literature around the topic of study. Chapter Three (3) outlines the method used in the study and the standard laboratory analytical procedures for the selected properties. Chapter Four (4) displays results and discussion and chapter Five (5) concludes and gives recommendation.

CHAPTER TWO

LITERATURE REVIEW

Maize

Maize (*Zea mays*) is one of the largest staple crops produced in Ghana. The precise application of production inputs that will preserve the environment as well as agricultural production is essential for successful maize production (Jéan, 2003). The demand for maize in Sub-Saharan Africa was projected to double by the year 2020 (Rosegrant *et al.*, 2001).

The crop was selected based on the fact that maize is the largest staple crop in Ghana. It also represents the second largest commodities of crops in terms of the area of which it is planted, which can cover about one million hectares of land, according to Schroth *et al*. (2016). The crop accounts for more than fifty per cent (50%) of the total cereal produced in Ghana whiles the annual yield is recorded as 1.1% (Bajzalj *et al*., 2014). Most of this account is produced on a small scale at 70% of the total, mostly grown marginal land with low inputs and low rain-fed throughout the country. Due to these poor conditions under which maize is cultivated, the average yield is approximately 1.7 M t h a^{-1} as against an estimated achievable yield of 6.0 Mtha^{-1} (Abdullai *et al*., 2013). Ecological areas in Ghana where Maize production is potentially high are the Guinea and Sudan savannah zones. However, Brong Ahafo, Eastern and Ashanti Regions record about 84% of cultivated maize in Ghana, with the remaining 16% cultivated in the Northern Region, (Obuobi & Barry, 2010). In such areas of high production of maize, the responsible factors are due to high sunshine which produces high solar radiation in the day, low temperatures in the night and minimal occurrences of disease according to

Grassini *et al*. (2011). Other biotic and abiotic factors put constraints on the yield, among them include striga parasitism, low soil nitrogen and drought (Shiferaw *et al*., 2011).

In terms of the choice, maize was also selected because monocotyledons (maize) respond differently to the impact of soil compaction and there is the need to investigate this occurrence in Ghanaian soils.

Soil Compaction

Soil compaction is the physical consolidation of the soil by an applied force that destroys structure, reduces porosity, limits water and air infiltration, increases resistance to root penetration, and often results in reduced crop yield (Wolkowski & Lowery, 2008). It's a dangerous and needless technique that stunts crop growth. The sensitivity of soils to compaction is determined by a variety of factors, the most important of which are texture and structure (Hakansson & Lipiec, 2000). However, because of its influence on soil compaction, soil water is the most significant component in making decisions concerning cultural activities (Défossez *et al*., 2003).

Factors affecting soil compaction

Bell and Donnelly (2014) identified Farm machinery and animal, water content of soil, texture and natural causes (anthropogenic) as some of the determinants of soil compaction.

Farm machinery and animal activities

Soil compaction is caused by natural, human and animal induced activities. Treading of wet soils by animals causes soil compaction (Drewry *et al*., 2008). Anthropogenic activities including use of agricultural machinery also induce compaction (Hadas, 1994; Soane and Van Ouwerkerk, 1998).

These activities are greater now than in the past due to the increased use of heavy farm machinery. On wet soils, wheels from heavy equipment cause the soil compaction which is the most yielding. The most yield limiting soil compaction is caused by wheels from heavy equipment, particularly on wet soils (Wolkowski & Lowery, 2008; McKenzie, 2010). According to Drewry *et al*. (2008), Wolkowski and Lowery (2008) and McKenzie (2010), the process of tillage induced soil compaction are as follows (i) when soils are cultivated continuously at the same depth. The weight of the tillage equipment (discs, wheels or cultivator shovels) causes compression of the soil and smearing at the base of contact between the soil and tillage implement (ii) If the applied force is great enough, soil aggregates are destroyed (iii) The result is a dense soil with few large pores that has poor internal drainage and limited aeration.

In addition, Lamande and Schjonning (2011) observed that the size and mass of tyres of the machines have increased by the farm machinery designers in order to keep the surface unit pressure relatively constant. The axle load also causes increase in compaction in the soil profile. Heavy traffic and machinery also modify the soil structure, closing the porosity of the soil and degrading the physical qualities. When applied stress exceeds soil structural pressure, the soil starts to collapse, decreasing soil water and aeration (Reznik, 2007).

The weight of large farm equipment like tractors, seeds carts, combined harvesters, tract and manure spreaders, cause wheel traffic compaction to a considerable debt within the root zone (DeJong-Hughes, 2009). The farm machineries, livestock and rain-drops cause increases in soil bulk density and reduce large soil pores (Abdollahi *et al*., 2014). In the same vein, Reszkowska *et al.* (2011) and Franzluebbers and Stuedemann (2008) noted that the trampling action of grazing livestocks result in higher bulk density and deterioration of soil structure. According to them, this reduces soil pore space and restricts water and oxygen movement which are signs of soil compaction.

Heavy traffic load and high-passing frequency of farm machinery, according to Batey (2009), causes damage to soil structure. Another observation made on the wheel load by Radford and Thornton (2011) is that the wheel load-carrying capacity can cause sub-soil compaction at a debt of 0.5 to 1.0m and very difficult to restore. A similar observation made by Hamza *et al.* (2011) is that the study increase in the weight of agricultural machinery and field traffic frequency within the last forty years has led to increased compaction of soil especial when the land is wet. Verhulst *et al.* (2010) also reported that traffic induce soil compaction on arable soil constitutes a major threat to agricultural productivity and the environmental quality of the soil, water and atmosphere especially when the land is wet. Batey (2009) observed a similar situation and posited that wet soils are most vulnerable to soil compaction during farm operation with heavy machinery. Soil tillage implements induce soil compaction just below the depth of tillage, especially when the soils are wet (Koch *et al*., 2008). Compaction in the layer which is caused by the tillage is mostly referred to as 'hard-pan' or 'plough-pan' and it occurs just below the plough-depth (Janssen & Lenartz, 2009). Botta *et al*. (2009) explained that the process of tillage induced soil compaction happens when soils are cultivated continuously at the same depth. Again, Turmel, Speratti, Baudron, Verhulst and Govaerts (2015) noted that soil compaction on an agricultural land as a result of tillage operation remove the protective residue from the soil surface, exposing the soil to natural environmental forces leading to soil crusting. Soil that is crusted can prevent water infiltration and restrict the emergency of seed germination (Blanco & Tourn, 2019).

Zhou *et al*. (2010) also observed that grazed land has greater density than land not grazed and suggested that the trading action of the cattle results in increased bulk density of the soil. In addition, soils that are frequently visited by animals for grazing also increase the compaction due to the exertion of force from their weight and stumping of their feet (Nawaz *et al*., 2013).

Soil water content

Duttmann *et al*. (2014) noted that when soil water content soil is low, the soil becomes stiff and difficult to compact. Similarly, as the soil water increases, the thickness around the soil particles also increases, resulting into cohesion among the particles and further allowing them to slide over one another resulting in a high degree of compaction (Sadras, 2009).

According Chowdhury and Hoque (2013) constant pressure over soil with increase water content brings about expulsion of air since there will be reduction in the cohesion among the particles. Hillel (2012) differently noted that the compactness of soil under a constant pressure or load increase progressively with increase in soil water content to a maximum value and decreases with increase in soil water content. Both Hillel (2012), and Chowdhury and Hoque (2013) however agree that the water content at this maximum value is known as optimum water content required for maximum compaction. The increase in soil compactness with increase in soil water beyond optimum water content for maximum compaction is due to close orientation of soil particles by water (Ampoorter *et al*., 2010) and further increase in water content beyond per plastic unit, soil behaves like a fluid and loses its load-bearing properties.

Soil texture

Jurry and Stolzy (2018) observed that bulk density of coarse soil is higher than fine soil because the total pore space of fine soil is higher than the density of coarse soil pores. With the application of constant pressure or load, compaction increases coarse-textured soil and decreases as the fineness of the soil increases (Pengthamkeerati *et al*., 2011). Another observation made by Jordan *et al*. (2010) is that a soil with a lot of fine particles, such silt and clay, will have smaller pore diameters and more penetration resistance at a lower bulk density than a soil with a lot of coarse particles. In their set-up, a soil with silt loam, having 19% macro-pore space and a measured penetration resistance of 2.5 bars at a bulk density of 1.4 g cm^{-3} was reported. Similarly, a coarser sandy loam with 28.9% macro-pore space and a penetration resistance of 1.2 bars at the same density was recorded. Because of this relationship, coarse-textured soil usually has higher compaction than fine-textured soil.

Natural or Anthropogenic causes

Alleto *et al*. (2010) alleged that the causes of soil compaction could be natural or anthropogenic. Natural causes are attributed to pressure exerted by the root of trees as well as precipitation and are limited to 5 cm of the top of the soil. Such anthropogenic causes are associated with the sampling and urban pressure on site and can compact the soil up to 20 cm while mechanical operation can compact the soil up to 60 cm (Cambi *et al*., 2015).

Soil compaction can be reduced through biological drilling, which uses root canals left by previous crops to lessen the effects of subsoil compaction on crop root growth (Cresswell and Kirkegaard, 1995; Williams and Weil, 2004). Chen and Weil (2011) observed that deep root channels (biological drilling) left by rapeseed cover crops were advantageous for maize root growth, particularly where soils were highly compacted. This enhanced the crop roots to access sub-surface soil water. Tillage is another practice that had been used in ameliorating soil compaction. It favours the development of soil fauna and their burrowing allows crop roots to bypass the resistance posed by compacted soils (Kemper *et al*., 2011). Sub soiling or mechanical aeration was used to overcome restrictions posed to root growth (Burgess, 1998). It increases soil macroporosity and air permeability, and reduces soil bulk density (McKenzie, 2010). It is unsuccessful in many instances but timing of the soil treatment is important to its success (Crush & Thom, 2011). Chisel ploughing has been used to improve nutrient uptake of crop plants. Raza *et al.* (2005) observed that chisel broken hardpan increased nitrogen uptake by 1.2 and 6 % over natural hardpan and 22 and 24 % over artificial hardpan (Raza *et al*., 2005). Cultivar improvement had been used to overcome the influence of soil compaction on root growth. Using traditional plant breeding methods, however, selecting crop cultivars with some tolerance to certain compacted soils is costly (Ghaderi *et al*., 1984).

The Effect of Soil Compactions on the Physical Property of Soils

Increased soil bulk density, decreased total porosity, soil aeration, and soil structure are all examples of the effects of soil compaction on soil physical properties (Pengthamkeerati *et al*., 2011) and these in turn affect soil water retention and hydraulic conductivity (Romero *et al*., 2011).

Impact of soil compaction on bulk density, aeration and porosity

Bulk density of soil is inversely proportional to soil total porosity (Carter & Ball, 1993), which is made up of the pore spaces available in the soil for the movement of air and water. The operational bulk density for plant growth is different for each soil (Cassel, 1982). Low bulk density (high porosity) leads to poor soil-root contact, and high bulk density (low porosity) reduces aeration and increases penetration resistance, limiting root growth (Cassel, 1982). Bulk density is related to soil organic matter, texture, structure and gravel content (Chen *et al*., 1998). Loss of soil organic matter leads to increased bulk density (NRC, 1993). High bulk density of subsoil layers may be harmful to root growth and development. Taylor and Brar (1991) reported that many different arrangements of compacted and loosened soil can occur in the cropped field which could affect the spatial distribution of roots not only in the plough layer but also in the subsoil.

One of the physical factors that restrict the development of root systems and growth and yield of crops on soils which are compacted is soil aeration (Czyz *et al*., 2001). Stepniewski *et al*. (1994) and Hakansson and Lipiec (2000) reported that the transient nature of insufficient aeration makes it difficult to attribute it to crop yield response due to soil compaction. Rab (2004) reported that macropore volume less than 10 % generally restricted root growth.

Impact of soil compaction on root growth and development

In both growing season (raining and dry), when rainfall is typically low and evapotranspiration is strong, soil compaction, particularly in the subsurface layers, may limit deep root growth and plant access to subsoil water (McKenzie, 2010; Chen and Weil, 2011). Muhammad *et al*. (2012) stated that the adverse effect of soil compaction on water flow and storage may be more serious than its direct effect on root growth.

Root patterns distribution affect root response to soil compaction. For best crop yields, a soil matrix with bigger holes is required (Lampurlanes & Cantero-Martinez, 2003; Crush & Thom, 2011).

Impact of soil compaction on root penetration

High soil strength reduces and even stops root growth (Atwell, 1993). The ability of soils to withstand deformation due to an applied force is measured by soil strength (Wolkowski & Lowery, 2008). It rises as soil particles are pushed together more closely. Plant roots must exert more power to penetrate the earth as soil strength increases. Soil water content and bulk density are the two most critical parameters that influence penetration resistance (Unger & Jones, 1998). Penetration resistance of a soil can be influenced by soil texture, organic matter (carbon), particle surface roughness and structure (Cassel, 1982; Campbell and O'Sullivan, 1991).

One of the most critical parameters determining root elongation and proliferation within a soil profile is mechanical impedance to root growth. Almost all roots developing through the soil experience it to some degree, and it slows down the pace at which oxygen is delivered to them (Bengough & Mullins, 1990). Roots take winding routes in search of the least amount of resistance in the soil. They can't get into pores that are smaller than their own. (Campbell & Henshall, 1991; Lampurlanes & Cantero-Martinez, 2003). Roots extract water from the soil, excrrete mucilage from around their tips, and swell when physically impeded (Bengough & Mullins, 1990). Roots face restrictive layers as they stretch deeper into the soil, causing them to spread laterally (Wolkowski & Lowery, 2008). Where subsoil compaction is high, roots may accumulate in loosen layer above the compacted zone. Jones *et al*. (1987) stated that a sure sign of compaction problems is roots growing horizontally along the top of a compacted layer. Chen and Weil (2009) observed higher root proliferation in the upper loose layer right above the compacted layer for rapeseed and rye.

Houlbrooke (1996) observed similar trend. The author reported that 80 % of root mass was located in soil depth of 5 cm. High soil compaction decreased the rate of root elongation due to both a decrease in the rate of cell division in the meristem, and cell length (Bengough & Mullins, 1990). Buttery *et al*. (1998) and Grzesiak (2009) reported that highly compacted soils affect the length of seminal adventitious roots, and the number and length of lateral roots and this eventually aggravates the effect of drought in reducing yield. Limited root growth (below biomass) as a result of soil compaction may reduce the potential for carbon sequestration in the soil (Lorenz & Lal, 2005). Tap-rooted species may penetrate compacted soils better than fibrous-rooted species and therefore be better adapted for use inbiological tillage (Chen & Weil, 2009). Some reports also suggest that plants with greater root diameters are better able to withstand compaction. Chen and Weil (2009) observed that roots with greater diameter may exhibit good penetration of compacted soils because of a combination of reduced overall friction and fewer tendencies to be deflected sideways. The development in root diameter in mechanically hindered roots is mostly due to an increase in cortical thickness, which is a function of both increased outer cell diameter and an increase in the number of cells per unit length of the root (Bengough & Mullins, 1990).

The root tip's penetration resistance recorded with the penetrometer is frequently 2-8 times higher than the root tip's actual resistance (Bengough and Mullins, 1990; Atwell, 1993) owing to the different ways by which roots and probes penetrate the soil. Roots continue to extend at greater penetration readings in well-structured soils or those in which bio-channels are intact, as in non-tilled soils, since they can grow in the inter-aggregated spaces (Taylor, 1983; Cresswell and Kirkegaard, 1995). Penetrometers, on the other hand, are rigid metal probes that must go in a straight line into the soil (Bengough & Mullins, 1990). Although careful interpretation of results and selection of penetrometer design are required if reliable predictions of soil resistance to root elongation are to be achieved, they remain one of the most convenient methods for estimating root resistance (Bengough & Mullins, 1990). Penetrometer readings greater than 2 MPa have been shown to cause considerable root development reductions (Atwell, 1993).

Root Penetration Ratio (RPR) could be a substitute approach to the use of penetrometer. The root penetration ratio is defined as the number of roots that exit the compacted middle core divided by the number of roots that penetrates the same core (Asady *et al.*, 1985). Ocloo (2011) observed that soil compaction reduced the root penetration ratio of maize seedlings.

Amendment of Soil Compaction

According to Mukherjee *et al*. (2014) soil amendment is the deliberate application of any chemical, biological or physical material to the soil for its physio-chemical condition in relation to plant growth or to improve the water holding capacity. Meehan *et al*. (2017) also defined amendment of soil as any form of nutrient source added to soil to improve its physical properties such as water retention, permeability, infiltration of water, drainage aeration and structure. McCauley *et al*. (2009) noted soil amendment comes in the form of either organic or inorganic. The organic amendment includes compost, mulch, peat moss, manure and bio-soils. Soil amendments are applied to the soils on farms as fertilizers or soil conditioners to improve conditions of soils to affect the physical properties of the soil and to provide the source of micro-organisms, nutrients and soil organic matter (Park *et al*., 2011). Organic amendment can be locally available and are lower in cost than inorganic amendment. Organic amendment helps in maintaining the soil structure and increases its nutrient-holding capacity (Sheoran *et al*., 2010). Organic amendment is easily degradable, environmentally friendly and ensures that the farm remains fertile for a long time (Sakeus, 2016). Organic amendment helps the soil to maintain its pH, making the field suitable for planting and are also cost-effective, according to Pandey and Singh (2010). However, Hempson *et al*. (2015) expressed a sceptical view of its content of primary nutrients like nitrogen, phosphorus and potassium (NPK).

Impact of soil amendments on crop growth

Nitrogen, phosphorus, and potassium (NPK) are the primary nutrients for plant growth (Gruhn *et al*., 2000). These primary nutrients are most often responsible for limiting crop growth when inadequate in soils used for crop production (Gruhn *et al*., 2000). The capacity of soils to be productive depends on more than just plant nutrients (Gruhn *et al*., 2000). The physical, biological, and chemical characteristics of a soil influence its fertility and soils differ in their quality because of these attributes (Gruhn *et al*., 2000). Some soils, because of their texture or depth are inherently productive and can store and make water and nutrients readily available to plants (Gruhn *et al*., 2000). On arable lands, continuous harvesting of crops interrupts the organic matter cycle and depletes nutrients in the soil (Baldantoni *et al*., 2010). Application of NPK fertilizer increased the yield of maize (Raza *et al*., 2005; Law-Ogbomo and Law-Ogbomo, 2009; Obidiebube *et al*., 2012).

Application of soil amendments to soil must be done judiciously as over application would lead to pollution and nutrient loss. Kimetu *et al*. (2004) and Crush and Thom (2011) suggested that split application of N and P should be implemented so as to decrease losses. Mutegi *et al*. (2012) reported that split application of mineral N resulted in minimal N leaching losses and better synchronization of nutrients to maize crop demand. Although significant studies have been made to advance the impact of soil amendments on crop growth and yield, there is need to understand and improve their efficiency in agricultural systems (Mutegi *et al*., 2012). One of such would be investigating its ameliorative impact on soil compaction.

Impact of soil amendments and compaction on crop nutrient uptake

The capacity of plants to acquire water and nutrients from the soil is related to their ability to develop extensive root systems (Chen & Weil, 2011). Limited water and nutrient availability due to soil compaction are major constraints to plant growth and yield in many soils (Raza *et al*., 2005). Soil compaction may induce nutrient deficiencies (Wolkowski and Lowery, 2008)). Lowery and Schuler (1991) reported that subsoil compaction decreased the nutrient uptake of N, P and K while Fe and Mn increased with increased compaction. Raza *et al*. *(*2005) observed that hardpan significantly reduced N, P and K uptake of maize. The addition of soil amendments can limit the effect of soil compaction on root growth by providing readily available nutrient to root systems that cannot extend deep into the soil due to the subsoil being compacted. Application of soil amendments restores soil quality by harmonizing pH, increasing water holding capacity, adding organic matter, , re-establishing microbial communities, and ease the impact of compaction (EPA, 2007). Application of soil amendments can thus increase the nutrient uptake of crops through the provision of readily available nutrients. As such, the use of soil amendments enables site remediation, revegetation, revitalization, and reuse (EPA, 2007). Mackay *et al*. (2010) reported that phosphate fertilizer inputs offset the negative effects of soil compaction on pasture growth. However, according to Crush and Thom (2011), compensating for the effects of soil compaction by increasing phosphate inputs could have a negative economic and environmental implication. It had been shown that soil to which compost has been applied or has not been tilled can be very resistant to compaction (Etana, 1995; EPA, 2007; Mackay *et al*., 2010). Hakansson and Lipiec (2000) reported that soil fertilization with N, P and farm yard manure improved the root density of barley in comparison with control plots.

Controlling Soil Compaction

Air permeability and reduced water infiltration are the major soil properties this is affected by soil compaction. Main physical negative effect to plant are restricted plant root growth and accessibility of nutrient due to increase in bulk density and reduced pore soil pore size. However, it is important to prevent soil compaction.

Avoiding tilling when soil is too wet or too dry

According to Batey (2009), the best way to control soil compaction is to make sure it does not happen, in the first place. Explaining further, Batey (2009) added that soil tilling must be avoided when it is too wet or too dry. According to Batey (2009) soil, when tilled, increase soil compaction since cohesion of soil particles is stronger when they are wet, thereby increasing compaction. On the other hand, he added that when the soil is too dry, the soil particles becomes too loose from one another that erosion by wind can result into loss of soil fertility. Hence, no tillage ameliorates soil compaction or favours the development of soil fauna and their burrowing to allow crop root to by-pass the resistance posed by compacted soils (McCormack *et al*., 2013). Cavaliery *et al*. (2019) said that no tillage also increases soil macro porosity and their permeability and reduces soil bulk density. In to the above, Crush and Thom (2011) also noted that even though it is successful in many instances, timing of soil amendment application is important to its success. Burgar *et al*. (2017) also reported that soil compaction can be controlled by avoiding heavy machinery including riding mowers or walking on planting beds.

Application of organic materials

Also, by adding organic materials like compost, peat moss, earthworm and gypsum, the compact soil can be amended and improve crop growth. Bowe (2011) also noted that by limiting traffic pressure caused by lawn mowers, vehicles with wider wheels and the application of mulch, farm yard manure, wood chips or even food scraps are cheap options that can be used to control compaction in lawns and garden. This can also be applied on the farm to correct soil compaction. More so, addition of organic matter such as compost, peat moss and cover cropping can also control compaction, observed by Zhou (2017) who also added that the root of cover crops can penetrate the compacted soil and loosen it. He also noted that by mixing compacted soil with compost, top mulching, tilling, grading and sub-soiling, drilling hard pan can break-up impermeable soil layer to improve drainage, plant root penetration, consequently amend compacted soil. Soane *et al*. (2012) also added that deep root channels left by rape seeds are advantageous for maize root growth, particularly, when soils are highly compacted. This enable crop roots to be able to access sub-surface water.

The strategies outlined above for controlling compaction have led to crop yield improvement although reservations with regards to their use still remain. Amending the soil with amendments helps to reduce the impact of soil compaction on crop growth (Bowden, 2006).

Burgar *et al*. (2017) also reported that soil compaction can be controlled by the application of mulching or compost as it protects the soil against compaction, while it helps to retain moisture and reduces weed competition. Counsel (2016) also found out that plots on which soil was ripped and amended with compost showed reduced soil strength as well and bulk density also reduced from 18 to 37% on soil plots with compost. Again, Counsel (2016) identified that when compost is added to compacted soil to a depth of 2ft. it decreases bulk density in the sub-soil, accelerate the process of soil formation and maintain long-term carbon storage resulting into increase in height of the canopy diameter of crops grown on compost amended soil.

How to Prepare Garden Compost

According to Kurtz (2019) composting is great for the environment and it can be easy to do with the right setup. Kurtz (2019) added that compost is created when organic matter reaches a point where it can no longer decompose. Kurtz (2019) said at this stage it becomes an extremely nutritious and long-lasting fertilizer. Kitchen scraps, old leaves, cardboard, and other suitable ingredients could be used to prepare a garden compost.

Methods of making compost

Haug and Ann (1994) said there are three different methods of making compost: using a composting bin, making a pile for composting and digging a composting trench.

Basic Principles of Composting

Alexandria (1994) noted that composting is the process of converting solid organic matter into a humus-like substance known as compost through controlled biological breakdown. Composting is the process of allowing nature to turn organic materials into a useful material for the environment. The procedure is aerobic, which means it necessitates the use of oxygen.

Various microorganisms, such as bacteria, actinomyces, and fungus, are used in the process to break down organic compounds into simpler chemicals. Leaves and branches that fall to the ground in natural settings provide a lush, moist layer of mulch that protects plant roots and provides a home for nature's most basic recyclers: worms, insects, and a slew of microscopic species that are too small to see with the naked sight. Composting is a practical method for processing solid waste for beneficial purposes while also eliminating germs, illnesses, and weed seed. The composting process may convert vast amounts of organic material into compost in a short amount of time by appropriately controlling air, moisture, and nutrients (Alexandria, 1994).

Microorganisms require oxygen while feeding on organic waste during composting. Active composting generates a lot of heat, and a lot of carbon dioxide and water vapour is emitted into the atmosphere. Composting reduces both the volume and mass of the raw materials while changing them into beneficial humus-like material, as carbon dioxide and water losses might amount to half the weight of the initial organic components. Composting is most efficient when the primary parameters that govern the composting process - oxygen, nitrogen, carbon, moisture, and temperature - are appropriately regulated (Alexandria, 1994).

Organisms Involved in the Composting Process

Pleasant (2012) recorded that in the early phases of "aerobic" composting, microbes conduct the majority of the job. Continuing, Pleasant (2012) added that in later stages larger organisms, such as fungi, sowbugs, pillbugs, centipedes, millipedes, spiders, earthworms, will assist the pile decomposition. The majority of the organisms that participate in the composting process are too tiny to see. Water, air, and organic material, which is their diet, are all necessary for them to exist. Organic matter is consumed by the organisms, which then create carbon dioxide, water, and heat. The heat phase, cooling phase, and maturation phase are all essential stages in the decomposition of a compost heap. The highest temperatures are found in the center of the heap during the hot phase. This has a sanitary benefit, as it kills pathogens and weed seeds that may be contained in organic materials (Pleasant, 2012)

The heap then goes through a cooling period, during which the fungi become more essential. Crop stems, for example, are a stiff fibrous material that they break down. Larger creatures, such as termites and worms, play a crucial role in breaking down and mixing material during the final maturation period (Pleasant, 2012). Pleasant (2012) explained that organisms are more active and organic materials are broken down more quickly in a hot climate than in a cold climate. The rate of decomposition is also affected by the type of organic matter employed and the pH of the soil.

Selecting the Right Materials

Almost all organic materials can be utilized to generate compost, according to Pleasant (2012), however various items will take different lengths of time to breakdown and form different end products. A balance of ancient and rough components ("brown materials") with young and juicy elements is required for a desirable result ("green materials"). This is due to the fact that different types of organic matter have varied carbon (C) and nitrogen (N) concentrations (N). Microbial development necessitates both carbon and nitrogen. Organic carbon (which accounts for around half of the mass of microbial cells) serves as an energy source as well as a fundamental cellular building element.

Pleasant (2012) suggested that while choosing materials for composting, it's necessary to evaluate the balance between the total amount of carbon and the total amount of nitrogen in the materials. The C/N ratio is the name for this equilibrium. Composting experts recommend a C/N ratio of roughly 30:1, or 30 parts carbon to each part nitrogen by weight. Nitrogen will be provided in excess at lower ratios and will be lost as ammonia gas, generating unpleasant odors. Higher nitrogen ratios indicate that there is insufficient nitrogen for proper microbial population growth, so the compost will remain chilly and decomposition will be delayed. Green and moist materials have a high nitrogen content, while brown and dry materials have a high carbon content.

Pleasant (2012) also mentioned that, because drying and weighing the things you place in your compost pile is impractical, you can adopt the basic guideline that compost should be around half "browns" and half "greens" by volume. Depending on the quantity and quality of the materials used, the ratio can be modified.

Improving the cation exchange capacity of the soil

The exchangeable cation capacity is the total number of exchangeable cations a soil can hold. The higher the exchangeable cation, the more cation the soil can hold. It is expressed in milliequivalent per 100 g of soil (me 100 g^{-1}) or in centimoles of positive charge per kilogram of soil (cmol kg^{-1}) which is numerically equal to 100 g^{-1}. The cation exchange capacity of the soil depends on the kind of clay and crop residue matter present.

If the roots are affected by compactness of the soil, then the ability of the root to siphon nutrients from the depth of soil for plant growth and development was also affected. Roots also suffer from increased anaerobic conditions in compacted soils and limit root functions such as crop anchorage and water uptake (Hatley *et al*., 2005). Moreover, soil compaction can reduce nodulation of leguminous crops such as soybean, which limited nitrogen nutrition of these crops (Siczek & Lipiec, 2011).

Summary of Literature Review

Reduction in porosity, limits water and air infiltration and increases resistance to root penetration which may result in reduction of crop yield. The aforementioned menace that reduced crop yield is caused by soil compaction. Nevertheless, both natural and artificial activities are the major causes of soil compaction. Some examples of natural causes include; pressure exerted by the root of trees, biological drilling, and soil texture whilst some examples of artificial causes of include water content during tillage, use of farm machinery and grazing of land.

The effect of soil compaction on soil physical properties is observed as increased soil bulk density, decreased total porosity, soil aeration and soil structure. Soil bulk density which is low and high porosity leads to poor soil-root contact whilst high bulk density and low porosity decrease aeration and increases penetration resistance, limiting root growth.

However, there is a remedy to soil compaction, which is amendment of the soil. Soil amendment upholds the primary nutrient of the soil (nitrogen, phosphorus and potassium). Soil amendment boosts the fertility of the land which supports root growth, high aeration and increase in root penetration.

Moreover, soil amendment increases crop's ability to develop extensive root system which support crop nutrient uptake.

Lastly, soil compaction can be controlled by avoiding tilling when the soil is too wet or dry and by application of organic matter.

Compacted soil amended with compost may support plant growth.

CHAPTER THREE

MATERIALS AND METHODS

Experimental Site

The experiment was established during the major and minor seasons in 2019 at the Teaching and Research Farm of the School of Agriculture, University of Cape Coast, in the Central Region of Ghana. The area is located in the coastal savanna agro – ecological zone. The average daily temperature in the area ranges between 23 °C and 32 °C while the annual rainfall over the region varies from an average of 800 mm to 1300 mm. The mean monthly relative humidity varies between 85% and 99% because of the sea breeze (Simons, 2016). The area has two rainy seasons for crop production – the major and minor seasons. The major seasons begins from March and ends in July with the peak in June while the minor season starts from September – November with the peak in October (Quagraine, 2014).

Experimental plot were located in a well-drained clay loamy soil classified as Benya Series or Ultisol by USDA. The soil pH is between 5.97 to 6.14. Due to continuous cultivation, the site is predominantly made up of grasses such as *Cyperus rotundus*, *Panicum maximum* and a few shrubs. The area has a history of vegetable production mostly garden eggs and okro with no application of either organic or inorganic fertilizer or adapting conventional tillage practices.

Experimental Design

The experimental design used was randomized complete block design (RCBD) with compaction as the main plot and composts applied as the subplots. The treatments used were four levels of soil compaction and three types of composts. The different levels of compaction imposed were no or 0 tractor pass, 3 tractor passes, 6 tractor passes and 9 tractor passes. The composts were maize compost (MC), cassava compost (CC) and pineapple compost (PC). The entire field was divided into four main blocks in which each block indicates one soil compaction level. Each block was also divided into three plots sub-plots with four replications (4 main blocks × 3 plots × 4 replications). The dimension for the entire field was 32m × 18m whiles each main block and sub-plot has 16m × 9m and 4m × 3m, respectively. Each sub-plot representing the replication has 4m × 3m as its dimension. Composts (MC, CC and PC) were randomly applied to each subplot. This can be seen at Appendix A.

Compaction Treatment

Before the compaction, bulk densities of the various blocks were taken to ascertain the level of compaction attained through bulk density values. On the 3 TP, the bulk density was 1.34 g cm^{-3} whilst the 6 TP had an average bulk density of 1.35 g cm^{-3}. On the 9 TP, the average bulk density was 1.45 g cm^{-3} and the NTP had an average bulk density of 1.27 g cm^{-3}.

The soil was compacted using a Massey Fergurson Farm Tractor. The weight of the tractor which was applied on the field was 2,540 kg and its length was 335 cm. As the tractor moves the weight of the tractor exert a certain pressure on the soil which will cause compaction. Therefore, the weight of the tractor will however increase the compaction of the soil and the more the tractor passes, the more the compaction. The tractor was made to run to and from over the field and this was considered as one tractor pass. The level of the compaction was then determined by taking the soil bulk density.

For the first block, there were 3 passes and the corresponding bulk density was 1.48 g cm^{-3}. On the second block, there were 6 passes with the corresponding average (1.55 g cm^{-3}) bulk density. On the third block, there were 9 passes and the corresponding average bulk density was 1.62 g cm^{-3}. On the fourth block, there were no passes with a corresponding average bulk density of 1.45 g cm^{-3}. The various blocks and their corresponding number of passes and bulk densities are presented in Table 1

Table 1: *Effect of compaction (after tractor passes) on soil bulk density*

Block	No. of passes	Bulk density
1st	3	1.48 g cm^{-3}
2nd	6	1.55 g cm^{-3}
3rd	9	1.62 g cm^{-3}
4th	0	1.45 g cm^{-3}

Compost Preparation

The compost materials used for the study were corn chaff, pineapple residue and cassava residue which were obtained as a by-product from the following sources; corn mill, fruit sellers and chop bar operators, respectively.

Materials used for the collection were bowls, wheel barrow and sacks. The bowls, wheel barrows and sacks were taken to the material collection point. The filled bowls were transferred into sacks for easy transport to the experimental site. The compost preparation started with ¾ kg of the cassava, maize and pineapple residue separately to ¼ kg of poultry manure. The compost was prepared by using black polythene sheets. The residue was weighed and spread on the polythene followed by the weighed poultry manure. These were then mixed together thoroughly after sprinkling 6 liters of water on it. The mixture was turned twice at intervals of two weeks to improve aeration. The working temperature was determined by inserting a long stick. If the stick was hot upon removal and touching it indicate that decomposition was still taking place but if the stick was cold upon it touching, means no breakdown or decomposition activity was occurring and the heap must be remade. The compost was ready for use in six weeks. About 1.2 kg of the cassava compost, maize compost and pineapple compost were weighed and applied on each of the four sub-plots.

Compost Application

The composts were applied before the soil was compacted. The treatment, maize compost (MC), cassava compost (CC), and pineapple compost (PC) were written once on sheets of paper and folded. The folded papers were placed in a container. The treatments were picked one after the other and assigned to the plots in a Block in the order in which they were picked from the container. After assigning treatments to all main plots, sub-plots followed similar reimmunization produced with replicator for compost. Each compost was randomly applied four times per treatment on the four main plots. Compost was applied by broadcasting method. Broadcasting method was done by evenly spreading each compost (cassava compost, maize compost and pineapple compost) on the surface of the four main plot by hand.

Test Crop

Maize variety used for the study was Obatampa. Maize seeds were sown after the soil was compacted. In furtherance, the seeds were sown in two seasons, thus major (raining season) and minor season (dry season) within

March to May and August to October respectively. The seeds for sowing were whole undamaged. The seeds were sown in rows with 2 seeds per hole. The planting depth was between 5-7cm. This planting depth gives better anchorage to the plant to resist wind damage (Sandinga & Woomer, 2009). The seeds were planted at the spacing of 90 cm by 40 cm.

This planting distance has been established to be is ideal during the dry season or the minor season. There were five rows of maize and each row has seven planting holes making a total plant population of 33 individual plants per sub-plot (1 ha).

Soil Sampling and Analysis

Soil samples which disturbed and undisturbed were taken at a depth of 0-15 cm before compaction and also after compaction when the test crop was two weeks old and at the cob development stage. Soil samples were randomly taken using auger. With the undisturbed samples, a core sampler was driven into the soil with a hammer and removed together with soil using earth chisel. The soil at both ends of the core sampler was trimmed with knife and placed on a lid. The core samples were used for determining bulk density. The composite soil samples for laboratory analysis were air-dried at room temperature, crushed with a pestle in a mortar and then sieved through a 2 mm mesh sieve. Soil samples sieved, were then used for the analysis of moisture, soil particle size distribution, hydraulic conductivity, pH, organic carbon, available phosphorus, total nitrogen, exchangeable potassium, cation exchange capacity and total porosity. These properties were analyzed at the laboratory of the Soil Science Department.

Particle size Determination

The Bouyoucos Hydrometer method as described by Bouycocos (1963) was used to determine particle size distribution. By this method, 50 g air-dried soil was put into a 500 mL cylinder and 125 mL distilled water was added and the mixture was swirled to wet the soil thoroughly. About 20 mL of hydrogen peroxide and a drop of alcohol was added to the mixture and the cylinder was gently swirled. The cylinder with the mixture was removed from the source of heat when the reaction had subsided and allowed to cool. About 2 g sodium hexameta-phosphate was then added to the mixture and shaken for 18 hours. The content of the mixture was then transferred to a 1000 mL sedimentation cylinder and distilled water was added to make up to the 1000 mL mark.

In addition, 2 g sodium hexametaphosphate was dissolved in water to form a blank solution of 1000 mL. The mixtures were corked and then shaken vigorously for about 10 minute and immediately Bouyoucos hydrometer was inserted into the mixture. The hydrometer reading was recorded at 40 sec. and 5 hrs. The sand, silt, and clay percentages of the soil were calculated as:

40 sec. (corr) = 2(40 sec. reading - 40 sec blank + T) (1)

5 hrs (corr) = 2 (5 hr. reading – hr blank + T) (2)

Where,

40 sec (corr) = the corrected reading of the hydrometer after 40 sec.

40 sec. reading = the hydrometer reading of the soil mixture after 40 sec.

40 sec. blank = the hydrometer reading of the blank solution after 40 sec.

5 hr. (corr) = the corrected reading of the hydrometer after 5 hrs.

5 hr reading = the hydrometer reading of the soil mixture after 5 hrs.

5 hr blank = the hydrometer reading of the blank solution after 5 hrs.

T = temperature.

For every °C above 20 °C, 0.3 was added to T, for every °C below 20 °C, -0.3 was added to T.

Percentage (%) sand = 100 – 40 sec (corr)

Percentage (%) silt = 40 sec (corr) – 5 hr (corr)

Percentage (%) clay = 5 hrs (corr).

Soil pH Determination

Soil suspension method was used to determine soil pH. About 10 g of air – dried soil sieved through a 2 mm sieve was weighed into a bottle with a screw cap. Then using measuring cylinder, 25 mL of water was added to the soil. The bottle was screwed and shaken for 15 minutes in a machine shaker. The bottle was removed and allowed to settle for about 5 minutes. The pH meter electrode was inserted into the suspension to take the readings and recorded.

Soil Organic Carbon Determination

Soil organic content was determined using the Walkley – Black method (Walkley & Black, 1934). A 0.5 g of soil sample was weighed and transferred into 500 mL Erlenmeyer flask. About 10 mL of $Kr_2Cr_2O_7$ solution was added to the content of the flask and swirled gently. Then 20 mL of concentrated H_2SO_4 was added and swirled gently for a minute. The flask was allowed to stand for 30 minutes. The addition of the H_2SO_4 caused heat to evolve which drove the reaction to conclusion. After 30 minutes of standing, the content of the flask was diluted with 200 mL of distilled water and swirled to ensure thorough mixing. Again, 10 mL of H_3PO_4, O_2 of NaF and 1 mL of diphenylamine, indicator were added. The H_3PO_4 was added to complex Fe^{3+} which otherwise would interfere with the end point. To get the green end point, excess Cr_2O_2 was titrated with 0.5 M Ferrous solution. A blank solution was made and titrated in the same way, using the same reagent but soil was omitted. Percentage Organic carbon was calculated using the formula,

$$\frac{(B-S) X\ Molarity\ of\ Fe^{3+} X 100 X 100}{Weight\ of\ the\ soil\ \ 77}. \qquad (3)$$

Where, B = Blank titre value, S = Sample titre value, 0.003 = Milliequivalent weight of carbon, $\frac{100}{77}$ = Factor converting the carbon actually oxidizing to total carbon, 100 the factor to change decimal to percentage.

Soil total Nitrogen Determination

The total nitrogen content of the soil was measured using the micro Kjeldahl method (Bremner and Mulvaney, 1982). 0.50 g of soil sample was weighed into a digestion tube, along with 1.1 g of mercury catalyst and 3 mL of concentrated H_2SO_4. The tubes were heated gently on a block digester until frothing subsided and the heat gradually increased to 380 ^oC to digest for about 2 hours. A steam distillation apparatus was set and the steam was made to pass through the solution for about 20 minutes after which the apparatus was flushed out. A 100 mL conical flask was filled with 5 mL of boric acid indicator solution and put under the condenser of the distillation apparatus. Through the trap funnel, an aliquot of the digested sample was transported to the reaction chamber. After adding about 10 mL of the alkali combination, distillation was started right away and continued until 40 mL of distillate was obtained. From a green to a wine red end point, the distillate was titrated against 140 M HCl. The sample titre value was subtracted from a digested blank, which was processed the same way. The formular below was used to calculate total nitrogen.

$$\%N = \frac{(B-S)X\ Solution\ value}{100\ X\ 100\ X\ aliquot\ X\ Sample\ weight}\ \% \qquad (4)$$

Where,

S = sample titre value

B = Blank titre

Soil Available Phosphorus (P) Determination

The Bray No.1 method was used to extract accessible phosphorus in the soil, and the ascorbic acid method was used to estimate p. (Oslen and Sommers, 1982). Reagent used for the reaction was ammonium fluoride (NH_4F), hydroxide (OH^-) and extracting solution. About thirty-seven millilitres of ammonium fluoride was dissolved in distilled water and then diluted to 1 litre. About 0.1 litres of concentrated HCl was diluted to 500 mL with distilled water. In a 15 mL centrifuge tube, 1 g of soil sample was weighed, and 10 mL of extracting solution was added to the soil. The mixture was then shaken for 5 minutes and filtered (Grade 595 Whatman filter paper with size 110 mm to 150 mm diameter circles and 580 × 580 sheets). Two millitres aliquot of the extract was pipetted into a 25 mL volumetric flask and from the stock, solution of p 100 mL prepared from the 5 µg P ml^{-1}. Again, from the 5 µg P ml^{-1} a set of working standards of P were prepared containing 0,0.1,0.2,0.4,0.6,0.8 and 1.0 µg P ml^{-1} in a 25 mL volumetric flask. It was ensured in the process that the blank and P standard contained the same volume of the extracting solution for the P test. About 10 mL of distilled water was added to each flask. A total of 4 mL of reagent B was added, followed by distilled water. The solution was left for ten minutes for a colour change to develop and their absorbance was determined on a spectrophotometer (UV5BIO) at 882 nm. The concentration and absorbance of the standard solution were used to plot a calibration curve. From the curve, the sample concentration was extrapolated. Available phosphorus was calculated using,

$$\mu g\ P\ g^{-1} \text{ of soil} = C \times \text{Dilution Factor} \quad (5)$$

where,

C = μg P ml^{-1} obtained from the graph.

Soil Cation Exchange Capacity Determination

The soil's cation exchange capacity was determined using Berthrong, Jobbagy, and Jackson's methodology (2009). A total of 5 g of soil was weighed before being added to a 50 mL centrifuge tube. Twenty five (25) mL of 1.0 *M* sodium acetate solution was added into the tube and a stopper was also inserted and shaken in a mechanical shaker for 5 minutes. The solution was then centrifuged until the supernatant liquid was clear. After that the liquid was decanted and the extraction was repeated for a number of times. The experiment was repeated with ethanol until the EC of the required decant read was obtained. The experiment was repeated again with ammonium acetate solution in order to displace the adsorbed Na^+. Thes decant was collected in a volumetric flask fitted with a funnel and filter paper and then topped up with ammonium acetate solution. The concentration was determined by flame photometer but in doing so, a series of standards of Na^+ was prepared that ranged from 0 – 10 melitre^{-1} of Na^+. A standard curve of sodium was prepared by plotting Na^+ concentration on the x – axis and the flame photometric reading on the y – axis. The sample extracted into the flame photometer was aspirated and the readings corresponding to the concentration of the Na from the standard curve was read.

Extraction of the Ca^{2+}, and Mg^{2+} was done by weighing approximately 0. 5 g of the sieved compost into 50 mL centrifuge tubes. Twenty mL of ammonium acetate (NH_4OAc) solution was added, shaken for 1 hour and allowed to stand overnight. The suspension was transferred into 100 mL conical flaks fitted with Grade 595 Whatman filter paper with size 110 mm to 150 mm diameter circles and 580 × 580 sheets. The compost trapped on the filter paper was successively leached with 20 mL of the NH_4OAc solution until 100 mL of the filtrate was obtained. Filtrate was used for the determination of Ca^{2+} and Mg^{2+}.

Maize Harvesting and Yield Determination

The crops were harvested manually with cutlass. However, cob formation was done for a period of eight weeks. The ears were carefully hand-picked and placed in a sack and the stalks were cut with a cutlass. On each plot, the harvested ears were placed into a different sack and then labeled before harvesting the next plot. The number of ears on each maize plant was taken into consideration. The husks were peeled off from the ears and the ears were placed into a labeled sack. Thereafter, the entire ears harvested from each plot was weighed to ascertain the fresh yield weight from the various plots. The ears were then sun – dried for a week to ensure better shelling. The total grains obtained from each plot was weighed to determine the total fresh grain weight of the plot. The grains were then safely stored for future use.

Statistical Analysis

Using the GenStat statistical program, the data collected on the various parameters was subjected to analysis of variance (12th Edition). When ANOVA indicated a significant difference, the least significant difference of 5% was utilized to compare the treatment averages. Each therapy was carried out four times in total.

CHAPTER FOUR

RESULTS AND DISCUSSION

Overview

This chapter gives details of the results obtained from the field and the laboratory work for major and minor seasons. It also addressed soil physical and chemical properties before and after compaction and compost application, the interactive effects of soil compaction and the compost on the soil physicochemical properties. The chapter also discussed the yield of maize under various soil compaction levels and with various compost types.

Initial Physical and Chemical Properties of the Soil for Major Season

Physical properties of the soil before compaction and compost application

From Table 2 the results of the physical properties of the top soil at the experimental site before treatment application showed that 50 % of the soil on the entire area was sandy loam, 25 % clay and 25 % sandy clay loam. The percentage of the silt differed from 13 % in Block 1 to 17 % in Block 3 but Block 1 recorded similar percentage silt to that of Block 4 (13 %). Blocks 1, 2 and 3 recorded high values of sand as compared to Block 4 which recorded a low value. The bulk density of 1.64 g cm^{-3}, 1. 66 g cm^{-3} and 1. 61 g were recorded for Block 1, Block 2 and Block 3, respectively. The generally higher bulk densities imply that the soil has less pore spaces because they have less organic matter and less aggregation. Bulk density above 1.6 g cm^{-3} impedes germination, root movement, plant growth rate, crop yield and the general performance of the crop (Jones *et al*., 2012). The bulk density values showing no significant difference means the blocks are homogeneous. The highest and lowest moisture contents were recorded in Block 4 and Block 1 showing

16.2% and 10.1%, respectively. The significantly higher moisture content found in Block 4 was due to the soil type since Block 4 was predominately clay and clay soil tends to have more micropores which allows the soil to hold more water or have higher water-holding capacity. This clearly implies that the water holding capacity of the soil is different among the blocks. This will eventually accelerate metabolic processes of the microbes in this soil. The hydraulic conductivity value was highest in Block 2 (1. 59 cm min^{-1}) and least in Block 4 (0.70 cm min^{-1}). This suggest that the soil in Block 2 will easily allow water to pass through (Asli & Neumann, 2009). The value for porosity and hydraulic conductivity among blocks indicates that there are significant differences among the blocks. Block 1 had the highest porosity and hydraulic conductivity. This means that, the soil on this block are more porous to allow for proper aeration and water movement which will eventually result in improved high crop yield compared to the other blocks.

Table 2: Initial physical properties of the soil

BLKS	Porosity (%)	BD (g cm^{-3})	HC (cm min^{-1})	MC (%)	Particle Size distribution			
					Sand (%)	Silt (%)	Clay (%)	TC
1	46.8	1.64	0.90	10.1	67.0	13.0	20.0	SCL
2	44.2	1.66	1.59	11.6	68.0	13.0	19.0	SL
3	45.2	1.61	1.39	13.7	70.0	17.0	13.0	SL
4	41.2	1.59	0.70	16.2	27.0	13.0	60.0	C
p value	*	>.05	*	*	***	>.05	***	
LSd(5%)	0.7	0.09	0.04	0.70	6.6	7.6	9.3	

p>.05= not significant, *= significant at p < 0.05**= significant at p < 0.01, ***= significant at p < 0.001.
Lsd = Least significant difference, BD = bulk density, M.C =moisture content, HC = hydraulic conductivity, TC= Textural class, SL= Sandy loam, C=Clay

Table 3: Initial chemical properties of the soil

BLKS	Ph (H_2O)	CEC $cmol_c\ kg^{-1}$	O.C (%)	Tot.N (%)	Avai.P (µg g^{-1})
3 TP	6.0	5.8	1.5	0.1	17.1
6 TP	6.0	5.9	1.1	0.9	17.9
9 TP	6.2	5.1	1.2	0.1	15.7
NTP	6.5	6.1	1.1	0.1	16.4
p value	**	*	*	**	**
LSd(5%)	0.25	0.2	0.3	0.4	0.7

Chemical properties of the soil before compost application

Some chemical properties determined for soils from the experimental plot before composts application are showed in Table 3. The pH of the soils in the various designated compaction plots varied from 6.0 to 6.5 in which no tractor pass (NTP) assigned block recorded the highest pH with 6.5 whiles three tractor passes (mild) assigned plot and the six tractor passes (moderate) assigned ones recorded the least with a pH of 6.0. The pH recorded for all the four assigned levels of compaction plots was conducive for maize production since maize tolerate a soil of pH between 5.2 and 8.0 in order to perform to the optimum (Coleman *et al.*, 2013). Phosphorus is important for crop growth and development and is likely to increase growth, yield and needed in larger quantity (Khan *et al.*, 2009). All the levels in compaction assigned plots exhibited different levels of available phosphorus ranging from 15.7 µg g^{-1} to 17.9 µg g^{-1}. This indicate adequate phosphorus to support plant growth and grain size (Sangina & Woomer, 2009). Nitrogen is among the plant nutrients needed in large quantities and almost for all crop growth (Smith *et al*., 2011). The total nitrogen among the soils in all levels of compaction assigned plots ranged from 0.1% to 0.9%. The high nitrogen contents present in the soil for all the level of assigned compaction could be ascribed to the cropping history of the site and since continuous cultivation of leguminous crops has been reported, this potentially may contribute to the high nitrogen content of the soil.

Compression is more likely in soils with low organic carbon concentration (Batey, 2009). This clearly indicates that soil organic carbon in a good proportion will decreases soil compaction. Three tractor passes (mild) assigned plots recorded the highest organic carbon with 1.5 %, followed by 9 tractor passes (high) assigned plots with 1.2 % whilst 6 tractor passes (moderate) assigned plots and no tractor pass (NTP) recorded the least organic carbon with a percentage of 1.1 %.

The CEC of the experimental site ranged from 5.1 $cmol_c\ kg^{-1}$ to 6.1 $cmol_c\ kg^{-1}$ with the least value recorded in 9 tractor passes (high) and the highest value recorded in no tractor pass (NTP). However, the value for CEC shows a high significant difference among the levels of compaction, meaning blocks are not homogeneous.

The pH and Organic carbon, nitrogen, phosphorus and potassium content of the compost

Some selected chemical properties of the maize, cassava and pineapple composts are showed in Table 4. The highest (33.9 %) organic carbon was recorded by the maize compost, followed by cassava compost (16.4%) and pineapple compost (15.6%). Maize compost again had the highest pH value compared to the other composts. Maize compost had higher nitrogen (N), phosphorus (P), and potassium (K) content than cassava and pineapple compost. Overall, maize compost had the highest untriats contents for NPK followed by cassava and pineapple composts.

Table 4: Selected chemical properties of composts used

Compost	pH (H_2O)	OC	N	P	K
		%			
MC	8.5	33.9	2.7	0.95	3.4
CC	7.1	16.4	1.5	0.4	1.2
PC	6.9	15.6	1.4	0.5	1.2

Physical properties of the soil after soil compaction and compost application

Some soil physical properties of the experimental site after treatments application are presented in Table 5.

Table 5: Effect of treatments on physical properties of the soil

Level of compaction	Treatment	Porosity (%)	Bulk density (g cm^{-3})	HC (cm min^{-1})	Moisture content (%)
Mild (Block 1)	Control	46.8	1.64	0.90	10.10
	CC	44.4	1.19	0.91	13.65
	MC	44.9	1.15	0.97	13.98
	PC	43.1	1.23	0.88	12.67
Lsd		1.2	0.08	0.04	0.46
Moderate (Block 2)	Control	44.2	1.66	1.59	11.60
	CC	42.6	1.26	0.86	12.89
	MC	43.8	1.20	0.89	13.40
	PC	41.7	1.29	0.83	12.08
Lsd		0.9	0.14	0.52	0.65
High (Block 3)	Control	45.2	1.61	1.39	13.7
	CC	42.4	1.35	0.81	12.03
	MC	43.0	1.33	0.84	12.09
	PC	42.1	1.39	0.78	11.21
Lsd		1.42	0.07	0.25	1.23
NTP	Control	41.2	1.59	0.70	16.20
	CC	45.1	0.98	1.11	15.58
	MC	45.7	0.86	1.24	16.73
	PC	43.9	1.00	1.08	14.31
Lsd		2.12	0.32	0.18	1.16

Treatment effects on Porosity

The highest porosity (%) for the mild compaction was 44.9 (%) that can be seen in the maize compost. The lowest porosity was the pineapple compost with the value of 43.1 (%). The control was 46.8 (%) which is the highest. The porosity reported by maize compost (44.9%) shows that pore volume of soil lies within acceptable values to allow for aeration and gas exchange (Homes,

2013) compared to all other treatments.

As compaction elevates to the moderate level, the porosity values were almost similar to the mild level. The greatest value was 43.8% and was found in maize compost treated plot. The lowest was in pineapple compost with the value 41.7%. Comparing the mean to the control of 44.2 we can confirm significant difference among the treatments with the MC indicating the highest value. This means that compost increased soils ability to favour aerobic activities and also allows for ease of percolation (U.S.D.A., 2016). From Table 5 the highest value for porosity was 43.0%which was obtained from maize compost and the least was 42.1% found for the pineapple compost plot. The control was 45.2%. Comparing the control with the mean, there was significant ($p < 0.05$) difference amount the treatments. The porosity percent reported by maize compost of 43.0% shows that pore volume of soil lies within acceptable values to allow for aeration and gas exchange (Home Guides, 2013), and that, regardless of the level of soil compaction, maize compost in relieving compaction was superior to other composts.

Table 5 indicates that the porosity within the no tractor passes section indicate a range of 43.9% to45.7% after compost addition. The highest porosity was obtained on plot with maize compost with the least value coming from pineapple compost plots. Overall, treatment with no tractor pass plots indicated an average of porosity 45.1%. The porosity reported by maize compost (45.7%) shows that pore volume of soil lies within acceptable values to allow for aeration and gas exchange (Home Guides, 2013). This means that maize compost increases soil ability to hold water both directly and indirectly.

Treatment effects on bulk density

The range of bulk density values was 1.19g/cm^3 to 1.15 g/cm^3. The least bulk density value obtained in cassava compost treated plots with the highest bulk density value obtained for the pineapple compost plots. The control had the value of 1.64 g/cm^3. Comparing the mean values of bulk densities recorded amongst treatments, it showed that there was a significant difference in the bulk density values recorded. Bulk density of 1.66 g cm^{-3} generally impedes germination, root movement plant grow rate and crop yield (Jones et al., 2012). From the results, maize compost helps in decreasing bulk density in mild compacted soil.

In the moderately compacted plot, bulk density values were higher than in the mild compacted plot. The greatest value for the moderate plot was 1.29 g/cm^3 and the lowest bulk density value was 1.20 g/cm^3 with the highest obtained from pineapple compost and the least bulk density value obtained from maize composts plot. The control was 1.66 g/cm^3. Bulk density of 1.66 g cm^{-3} generally impedes germination, root movement plant grow rate and crop yield (Jones *et al.*, 2012). MC decreased bulk density compared to all other compost treatments. This indicates the ability of maize compost to relieve compaction in a moderately compacted soil.

Soil compaction enhanced from moderate to the highest level with 9 tractor passes. The bulk density values recorded ranges from 1.33 g/cm^3 to 1.39 g/cm^3. Amongst the compost treatment the highest bulk density value obtained was in pineapple compost plots and the lowest bulk density was from the maize compost plot. The control was 1.61 g/cm^{3}and it falls beyond the highest bulk density acceptable for improve crop productivity. A bulk density range of 1.0 to 1.8 g/cm3 is considered appropriate. Jones *et al.* (2021) noted that bulk density above 1.6% g/cm^3 is detrimental to the growth and productivity of crops. Again, the MC amendment significantly reduced high bulk density effect on the soil thereby improving the general condition agricultural soil for plant growth and development.

Where there were no tractor passes plots values of bulk densities were least compared to where there has been tractor passes. The highest figure was 1.0 g/cm^3 and the least was 0.86 g/cm^3. The highest value was obtained for pineapple compost while the least value was for maize compost. The mean bulk density value of all compost treatment compared as compared to control gave a significant ($p < 0.05$) difference.

Treatment effects on hydraulic conductivity

The hydraulic conductivity values ranged between 0.97 min^{-1} and 0.88 min^{-1}. The highest hydraulic conductivity value was obtained in the maize compost plots with the lowest obtained for the pineapple compost plots. The least mean value when compared to the control can be said to be significantly lower. This implies that MC helps a mildly compacted soil in improving the water conductance ability.

In the moderately compacted plots, hydraulic conductivity ranged from 0.89 min^{-1} to 0.83min^{-1}. The highest value was obtained in maize compost plots and the lowest value from pineapple compost plots. The control had a value of 1.59 min^{-1} which is greater than the hydraulic conductivity value of maize compost plots. This means that the control had more ability to transmit fluid through pore spaces than the compost treatment plots.

Improving soil compaction from moderate to high level reduce the compost impact. The range of hydraulic conductivity values was 0.84 min^{-1} to 0.78min^{-1}. The highest value was for maize compost and the least value was for pineapple compost. There is no significant difference amongst the compost treatments on hydraulic conductivity. This implies that, the positive effects of compost achieved by maize compost ceased to apply under these circumstances. The range of hydraulic conductivity values for no tractor passes were 1.24 min^{-1} to 1.08min^{-1}. The highest was from maize compost whiles the lowest value was from pineapple compost. The control recorded a hydraulic conductivity value of 0.70 min^{-1} which is lesser than the hydraulic conductivity values for all the compost treatments. This clearly indicates the increment of hydraulic conductivity value for all the compost treatments though the maize compost plots had more ability to transmit fluid through pore spaces.

Treatment effects on soil moisture contents.

For the mild compacted soil, the range of soil moisture contents ranged from 12.67% to 10.10%. The highest moisture content which was from maize compost with the least was from the control. There was a significant difference ($p < 0.05$) amongst compost treatment. The maize compost and the pineapple compost have a high water content than the control.

In the moderately compacted soil the highest moisture contents was 18.40% and the least was 12.08%. The highest value was from the maize compost and the least value was from the cassava compost. The control value for moisture content was 11.60% which does not fall within the highest and the lowest values. The increase in moisture content is as a result of compost addition of and other environmental factors.

The highest value was 12.09% and the lowest value was 11.21% the highest value is coming from the maize compost and the lowest value is coming from pineapple compost. The control was 18.7% and does not fall within the highest value and the lowest value the change in value is due to the application of compost to the various compaction levels. This means that compost increases soils ability to hold water both directly and indirectly (U.S.D.A, 2016).

The highest value of soil moisture content for NTP was 16.73 % and the least value was 14.3%. The maximum value was from maize compost and the lowest was for the pineapple compost the control was 16.20% which falls within the highest and the lowest values. The significant value was 1.16%. High values of moisture content in the no tractor pass may be due to natural rainfall. In conclusion the best level of compactions amelioration is the NTP and maize compost is the best amongst the other compost treatments.

Chemical properties of the soil after soil compaction and compost application

Some chemical properties of the soil as affected by the various composts applied are presented in Table 6

Table 6: Effects of treatments on chemical properties of the soil

Level of compaction	Treatment	pH (H_2O)	CEC ($cmol_c$ kg^{-1})	O.C (%)	Tot.N (%)	Avai.P (μgpg^{-1})
	Control	6.00	5.80	1.50	0.10	17.10
Mild	CC	6.50	6.04	1.38	0.32	22.56
(Block1)	MC	6.55	6.20	1.41	0.40	23.18
	PC	6.34	5.89	1.37	0.28	22.18
Lsd		0.24	0.27	0.08	0.19	3.89
	Control	6.00	5.90	1.10	0.90	17.90
Moderate	CC	6.40	5.72	1.34	0.24	21.70
(Block 2)	MC	6.54	5.81	1.35	0.29	22.43
	PC	6.20	5.71	1.31	0.20	21.20
Lsd		0.09	0.11	0.07	0.54	1.12
	Control	6.20	5.10	1.20	0.10	15.70
High	CC	6.30	5.53	1.24	0.18	20.51
(Block 3)	MC	6.35	5.67	1.28	0.19	20.80
	PC	6.12	5.39	1.13	0.17	19.25
Lsd		0.02	0.23	0.09	0.04	2.49
	Control	6.50	6.10	1.10	0.10	16.40
NTP	CC	6.55	6.47	1.47	0.60	24.36
(Block 4)	MC	6.60	6.58	1.49	0.77	24.68
	PC	6.40	6.26	1.46	0.52	23.20
Lsd		0.05	0.03	0.28	0.43	5.03

Treatment effects on pH.

The highest pH value ranged from 6.55 to 6.34. The highest value was coming from maize compost and the least value was coming from pineapple compost. The pH value below 4 inhibit the absorption of calcium magnesium, molybdenum and phosphorus (PSS, 2014). This shows that the pH of 6.00 for control is above 4 hence it will improve the absorption of calcium magnesium, molybdenum and phosphorus. The ideal pH range for most plants is between 5.5 and 7.0. (PSS, 2014). The pH values for treatments within the mild level of compaction fall within the optimum range and are good for crops growth. Maize compost has increased pH compared to that of the control.

The highest pH for moderately compacted soil was 6.54 with the least being 6.20. Maize compost yielded the most value, whereas pineapple compost yielded the lowest. The control plot had 6.00 which was close to the lowest in this category. This means that maize compost has increased the pH at the moderate level than the control. In addition, the pH values for all treatment fall within the acceptable range of 5.5 to 7.0 (PSS, 2014) which are good indications for crops growth.

In the highly compacted treatment, the highest pH of 6.35 and the lowest was 6.12. The highest value was coming from maize compost and the lowest value was coming from pineapple compost. The control was 6.20 which falls within the acceptable range of 5.5 to 7.0 (PSS, 2014) which is a good indications for crops growth.

The highest pH value for the no tractor pass was 6.60 and the lowest value was 6.40. The highest value came from maize compost and the lowest value from pineapple compost. Maize tolerates a soil of pH value between 5.2 and 8.0 in other to perform to its optimum (Coleman *et al*., 2013). This shows that the pH values for treatments within the blocks fall within the acceptable pH range making it suitable for optimum growth of maize.

In conclusion, the pH within the no tractor section indicates a range of 6.40 to 6.30 after compost addition the highest pH was obtained on plots with maize compost with least value coming from pineapple compost plots. Low soil pH value below 4 inhibit the absorption of calcium, magnesium, molybdenum and phosphorus. This shows that the range of values for pH within the no tractor pass section are above 4 and the said to be slightly acidic and good for crop growth.

Effect of compaction and composts on CEC

The highest CEC was 6.20 $cmol_c$ kg^{-1} and the lowest was 5.89 $cmol_c$ kg^{-1} in the mildly compacted block. The highest value was from maize compost and the lowest value was coming from pineapple compost. All treatments had higher CEC values compared to control treatment (5.80 $cmol_c$ kg^{-1}). This shows that there is an improvement in CEC after the application of the various composts. Cation exchange capacity (CEC) is a helpful soil fertility indicator since it reveals the soil's ability to supply critical plant nutrients including calcium, magnesium, and potassium (Rebecca and Kelly,.2003)

In the moderately compacted soil, the highest CEC was 5.81 $cmol_c$ kg^{-1} and the lowest was 5.71 $cmol_c$ kg^{-1}. The highest value was from maize compost and the lowest value was coming from pineapple compost. The control treatment (5.90 $cmol_c$ kg^{-1}) had a higher CEC compared to all the treatments.

In the highly compacted plots, the highest CEC was 5.67 $cmol_c$ kg^{-1} and the lowest was 5.39 $cmol_c$ kg^{-1}. The highest value was from maize compost and the lowest value was coming from pineapple compost, although significantly higher CEC value compared to control treatment (5.10 $cmol_c$ kg^{-1}). This shows that there is an improvement in CEC after the application of the various composts.

In the no-tractor pass treatments, the CEC ranged from 6.26 $cmol_c$ kg^{-1} to 6.58 $cmol_c$ kg^{-1} after compost application. The highest CEC was obtained on plot with maize compost with the least value coming from pineapple compost plot. All treatments impacted a higher CEC compared to control treatment (6.10 $cmol_c$ kg^{-1}). This shows that there is an improvement in CEC after the application of the various composts. Again, due to high CEC value for maize compost plot, it had higher potential to supply important nutrients such as calcium, magnesium and potassium to plant (Rebecca and Kelly, 2003) compared to the other compost treatment plots.

In conclusion, the CEC of the experimental site m ranged from 5.1Cmolkg to 6.1Cmolkg with the least value recorded in high tractor passes and the highest value recorded in no tractor pass. However, the value for CEC show a high significant difference among a levels of compaction meaning blocks are not the same.

Effect of compaction and composts on organic carbon contents

The organic carbon within the mild section has a range of 1.37% to 1.41% after compost application. The highest organic carbon was obtained on plot with maize compost with the least value coming from pineapple compost plot. Agricultural topsoil has an organic carbon concentration ranging from 1% to 6% (SARE, 2013). The organic carbon recorded by all the composts fall in the acceptable range and also helps give soil its water-retention capacity, its structure, and its fertility (Schwartz, 2014). Even though the control treatment (1.50%) also falls within the acceptable range.

In the moderately compacted blocks maize compost has the highest organic carbon of 1.35% with pineapple compost recording the lowest organic carbon contents of 1.31%. There was an increase in organic carbon contents for all composts treatment. The increased could may be as results of the direct enrichment of the soil by the compost. Nevertheless, organic carbon recorded by all the composts give the soil improved ability to retain water, improved structure, and fertility (Schwartz, 2014).

The organic carbon within the highly compacted section ranged from 1.13% to 1.28% after compost application. The highest organic carbon was obtained on plot with maize compost with the least value coming from pineapple compost plot. Agricultural topsoil has an organic carbon concentration ranging from 1% to 6% (SARE, 2013). The organic carbon reported by all the composts fall in the acceptable range and this potentially improves water-retention capacity, structure and fertility (Schwartz, 2014). Even though the control treatment (1.20%) also fall within the acceptable range, there is an increase in organic carbon content for all treatments

In conclusion, Organic carbon within the no tractor pass section has a range of 1.46% to 1.49% after compost application the highest organic carbon was obtained on plots with maize compost with the least value coming from pineapple compost plots the organic carbon content of agricultural topsoil is usually in the range of 1% to 6%. the organic carbon reported by maize compost, 1.4 9% fall in the acceptance range and also helps give soil it's water retention capacity, its structure and its fertility. in addition, pineapple compost had the least organic compost of 1.46% also fall within the acceptable range. Even though the control treatments 1.1% also fall within the acceptable range there was an increase in organic content for treatment this may be attributed to the already existing organic carbon in other compost before its application the LSD value for organic carbon on no tractor pass s shows a significant difference among treatments which me that there will be an improvement in soil aeration, drainage of water and reduces the risk of erosion and leaching of nutrient. Moreover, the high level of compaction section also reported a range of 1. 13 present to 1.28% of organic carbon which fall within the acceptable rates and it's LSD value also indicates a significant difference. The compaction effects resulted in decrease in cation exchanged capacity of the soil.

In the no-tractor pass treatment, maize compost has the highest organic carbon of 1.49% with pineapple compost resulting in least organic carbon of 1.46%, indicating a slightly higher contents than the control treatment (1.10%). There was an increase in organic carbon for all treatments after compost application. This could be attributed to the already existence of organic carbon in all the composts before its applications. Moreover, organic carbon reported by all the composts fall in the acceptable range and also helps give soil its water-retention capacity, its structure, and its fertility (Schwartz, 2014).

Effect of compaction and composts on soil total nitrogen contents

The total nitrogen contents of soil in the mild compacted section indicated a range of 0.32% to 0.40% after compost application. The highest nitrogen content was obtained on plots with maize compost with the least coming from pineapple compost plot. All treatments have a higher nitrogen content as compared to control treatment (0.10%). This shows that there is an improvement of total nitrogen content of soil after the application of the various composts. Nitrogen is among the plant nutrients needed in large quantity and almost for all crop growth (Smith *et al.*, 2011)

The soil total nitrogen content recorded by moderate level of compaction ranges from 0.20% to 0.29% after compost addition. The maize compost plot recorded the highest nitrogen content followed by cassava compost plot and pineapple compost plot. The values recorded by individual treatment is higher when compared to the control treatment (0.90%). This shows that, after the compost application the soil was able to regain more nitrogen content in moderate level of compaction. Maize compost plot as the highest recorded value of soil total nitrogen will help the leaf of the plant to grow well (Sangina and woomer., 2009) compared to the other treatment plots.

Maize compost has the highest nitrogen content of 0.19% within the high level of compaction whilst pineapple compost has the lowest nitrogen content of 0.17%. The values reported by individual treatment is higher when compared to the control treatment (0.10%). This shows that, after the compost application the soil was able to regain more nitrogen content in moderate level of compaction. This shows that maize compost improved total nitrogen content than the control treatment. Nitrogen is among the plant nutrients needed in large quantity and almost for all crop growth (Smith *et al*., 2011)

Soil total nitrogen in the no-tractor pass section indicate a range of 0.52% to 0.77% after compost application. The highest nitrogen was obtained on plots with maize compost with the least value coming from pineapple compost plots. Overall, regardless of treatment with no tractor pass plots, total nitrogen averaged 0.63%. The nitrogen content reported by maize compost (0.77%) shows that soil will be able to support plant growth, plant food processing and the creation of chlorophyll (Smith *et al*., 2011). The value of nitrogen content reported by pineapple compost (0.52%) will also support plant growth but not in abundance a the maize compost due to its percentage obtained as compared to the percentage of maize compost.

In conclusion, the nitrogen content within the mild level of compaction section indicate a range of 0.28% to 0.40% after compost addition. The nitrogen contents reported by maize compost, 0.40, in mild level of compaction is higher than the nitrogen content reported by maize compost, 0.1 9 present in high level of compaction and this runs through the other levels of compaction. This shows that after the compost application the soil was able to regain more nitrogen content in mild moderate and high level of compaction but not as more as no tractor pass because the tractor pass has little or no bulk density.

Effect of compaction and composts on available phosphorus

Available phosphorus in the mildly compacted section ranged from 22.18 µgpg $^{-1}$ to 23.18 µgpg $^{-1}$ after compost application. The highest available phosphorus content was obtained on plot with maize compost with the least value from pineapple compost plot. An acceptable range for available phosphorus content for optimal growth of crop is between 10 µg g $^{-1}$ to 40 µg g $^{-1}$ (Sangina & Woomer, 2009). The treatments show that the available phosphorus resulting from their application to soil is capable of speeding flowering process and increasing grain size (Sangina & Woomer, 2009) since it they fall within the acceptable range. However, MC and PC resulted in significantly higher available phosphorus contents.

Maize compost treatments resulted in the highest available phosphorus contents of 22.43 µgp g $^{-1}$ with pineapple compost recording the lowest available phosphorus contents of 21.20 µgp g $^{-1}$. An acceptable range for total phosphorus is 10 µg g $^{-1}$ to 40 µg g $^{-1}$ (Sangina & Woomer, 2009). This shows that the available phosphorus contents recorded by all the treatments will help speed flowering process and increasing grain yields (Sangina & Woomer, 2009).

In the highly compacted soil available phosphorus ranged from 19.25 µgp g $^{-1}$ to 20.80 µgp g $^{-1}$ after compost application. The highest phosphorus contents was obtained on plot with maize compost with the least value obtained from pineapple compost plot. An acceptable range for total phosphorus is 10 µgp g $^{-1}$ to 40 µg g $^{-1}$ (Sangina & Woomer, 2009). This shows that the phosphorus reported by all the treatments will be capable of speeding flowering process and increasing grain size (Sangina & Woomer, 2009). The available phosphorus contents for the control treatment was 15.70 µgp g $^{-1}$ which also falls within the acceptable range as reported by (Sangina & Woomer, 2009) and compost application generally increased available content this is due to the potential increase in pH resulting in higher releases of soil available phosphorus contents.

In the no-tractor pass treatment, compost had the highest available phosphorus of 24.68 µgp g $^{-1}$ with pineapple compost showing the lowest available phosphorus of 23.20 µgp g $^{-1}$. An acceptable range for total phosphorus is 10 µg g $^{-1}$ to 40 µg g $^{-1}$ (Sangina & Woomer, 2009). This shows that the phosphorus recorded by all the compost treatments will be capable of speeding flowering process and increasing grain size (Sangina & Woomer, 2009). Again, there was an increment in the value of available phosphorus in all the compost treatments compared to control value. This may be attributed to addition of compost to the no tractor pass plot.

In conclusion, the acceptable range for total phosphorus is 10 micrograms per gram to 40 micrograms per gram (Sangina & Woomer, 2009). The phosphorus reported by maize compost, 24.68 micrograms per gram show that soil will be capable of speeding flowering process and increasing grain size. Moreover, phosphorus reported by pineapple compost, 23.20 micrograms per gram fell within the acceptable range hence it will boost soil capacity of speeding flowering process and increasing grain size (Sangina & Woomer, 2009).

The grain yield of maize for the various compacted area with composts

Harvested maize from the various compacted area with compost were weighed and the results are showed in Table 7.

Table 7: Weight of harvested maize on the various compacted plots with compost

Compost	NTP(kg/ha)	Mild(kg/ha)	Moderate(kg/ha)	high(kg/ha)
MC	11.58	10.69	7.95	6.65
CC	9.91	9.12	7.05	5.01
PC	8.11	7.89	6.70	3.64
Total	29.60	27.70	21.70	15.30

The maize compost as an amendment resulted in 11.58 kg/ha of maize yield which has the highest in NTP followed by cassava compost (9.91 kg/ha) and pineapple compost (8.11 kg/ha). In all compaction levels, maize compost remained the treatment amongst the composts with the highest impact on maize yield. These results are consistent regardless of soil compaction level (Table 7). However, in terms of yield outputs from the various levels, of soil compaction, the yields of maize recorded have been 29.6, 27.7, 21.7 and 15.3 kg/ha maize yields for NTP, mild, moderate and high, respectively (Table 7).

Initial Physical and Chemical Properties of the Soil for Minor Season

Physical properties of the soil before compaction and compost application

Table 8 shows that the particle size distribution for sandy soil recorded the highest percentage in all the blocks as compared to silt and clay. However, block 3 recorded a percentage of 69.5 % which is the highest among the other blocks. Block 3 recorded a high value of silt followed by block 2 and block 4 whilst block 1 recorded the least percentage (12.4 %) of silt. In addition, Table 8 shows that block 4 recorded 47.5 % of clay soil which is the highest amongst the other blocks.

Because germination, root movement, plant development rate, and crop production are hampered by a bulk density of 1.6 g cm-3 (Jones et al., 2012), the bulk density for the various block in Table 8 will support plant growth rate and general performance. It is however recorded in Table 8 that block 1 observed the highest bulk density and block 3 observed the lowest bulk density as compared to the remaining blocks. This suggest that block 3 will support plant growth more than block 1. The porosity for block 3 (44.5 %) is the highest followed by block 2 (43.2 %), block 4 (43.1 %) and block 1 (42.4 %) respectively. Table 8 clearly indicates that as bulk density decreases, porosity increases and as the bulk density increases, porosity decreases. The values for porosity and bulk density signifies that the soil will be able to support plant growth.

Again, the lowest and the highest moisture contents were recorded in Block 4 and Block 1 showing 14.5% and 11.3% respectively. Block 4 had a significantly moisture content due to the soil type, that is clay and clay soil have a tendency to have extra micropores which permits the soil to have higher water-holding capacity. The water retention of the soil is different amongst the blocks as the values recorded in Table 8 indicated. The value of hydraulic conductivity in Block 2 (1.40 cm min^{-1}) is the highest and the least is Block 1 (0.7 cm min^{-1}). This means that the soil in Block 2 will easily allow water to pass through compared to the other blocks.

Table 8: Physical properties of the soil at the study site before treatment application

BLKS	Porosity (%)	BD (g cm^{-3})	HC (cm min^{-1})	MC (%)	Particle Size distribution			
					Sand (%)	Silt (%)	Clay (%)	TC
1	42.4	1.56	0.70	11.3	65.7	12.4	21.9	SCL
2	43.2	1.42	1.40	12.4	66.0	14.9	19.1	SL
3	44.5	1.34	1.31	13.9	69.5	15.3	15.2	SL
4	43.1	1.47	0.80	14.5	40.0	12.5	47.5	C
p value	***	**	***	***	***	NS	***	
LSd(5%)	0.68	0.12	0.06	0.76	5.6	7.1	8.1	

Lsd = Least significant difference, BD = bulk density, M.C =moisture content, HC = hydraulic conductivity, TC= Textural class, SL= Sandy loam, C=Clay

Chemical properties of the soil before treatment application

Some chemical properties of the soil before compaction and compost application are presented in Table 9.

Table 9: Initial chemical properties of the soil

BLKS	pH	CEC cmol$_c$ kg^{-1}	O.C (%)	Tot.N (%)	Avai.P (µgp g^{-1})
1	5.7	5.6	1.2	0.2	16.3
2	5.8	5.7	0.8	1.1	15.5
3	5.9	5.3	1.1	0.3	14.6
4	6.2	6.0	0.9	0.2	13.4
p value	**	**	**	***	***
LSd(5%)	0.3	0.26	0.27	0.32	0.64

NS= not significant, *= significant at $p < 0.05$**= significant at $p < 0.01$, ***= significant at $p < 0.001$. O.C = organic carbon, Tot. N = total nitrogen, Avai. *p*= available *p*. Lsd = Least significant difference

The soil pH values in Table 9 ranged from 5.7 to 6.2 with block 4 (6.2) having the highest value and the least is block 1 (5.7). The pH values recorded for all the levels of compaction plots was conducive for maize production since maize tolerate a soil of pH between 5.2 and 8.0 in order to perform to the optimum (Coleman *et al*., 2013).

The values for CEC before compost application ranged from 5.3 cmol$_c$ kg^{-1} to 6.0 cmol$_c$ kg^{-1}. Block 4 recorded 6.0 cmol$_c$ kg^{-1} for CEC which is the highest among the other levels of compaction and the least is Block 3. All the levels compaction recorded some amount of CEC and that shows that soil on all the blocks is fertile since CEC demonstrates the potential to provide essential plant nutrients including calcium, magnesium, and potassium (Rebecca and Kelly, 2013).

Moreover, Block 2 recorded 0.8 % for organic carbon which is the least among the other levels of compaction. Even though block 4 had the highest value for pH and CEC, its value for organic carbon wasn’t the highest. Table 9 shows that block 3 (1.1%) had the highest value of organic carbon compared to the other levels of compaction. Compression is more likely in soils with low organic carbon concentration (Batey, 2009). This clearly indicate that soil organic carbon in a good proportion will decrease soil compaction. The organic carbon content of agricultural topsoil usually in the range of 1% to 6% will support plant growth (SARE, 2013) and this is contrary to Block 2 (0.8%) and Block 4 (0.9%).

One of the chemical nutrients responsible for the leaf development is nitrogen (Sangina & Woomer, 2009). The total nitrogen among the soils in all levels of compaction ranged from 0.2% to 1.1%. This shows that nitrogen contents present in the soil for all the level of compaction is high and will support plant growth. However, Block 2 recorded the highest value of total nitrogen among the other levels of compaction and the least are Block 4 and Block 1.

Sangina and Woomer (2009) advocates that phosphorous have electron transport and nucleic acid synthesis as a principle metabolic role which is responsible for speeding flowering process and increasing grain size. The values for available phosphorous show significant difference among the levels of compaction, this means that available phosphorous will support plant growth hence increase in grain size. Block 1 had 16.3 (µgp g^{-1}) available phosphorous which is the highest among the levels of compaction.

The pH, Organic carbon, total nitrogen, phosphorus and potassium content of the composts.

Maize compost had the highest value for pH followed by cassava compost and pineapple compost. Again, maize compost contains 30.5 % organic carbon which is the highest compared to the other composts and pineapple compost (14.4%) recorded the least. Lack of nitrogen in soil will causes basal leaf chlorosis (Sanginga & Woomer, 2009). Table 10 clearly indicates that all composts that will use to ameliorate soil compaction already contains some level of nitrogen that will support plant growth. The percentage of nitrogen for maize compost is the highest among all the compost used as amelioration. A study conducted by Iren, Ediene and Akpan (2015) on the In an ultisol in south-eastern Nigeria, the effects of cassava peels and poultry manure-based compost on soil characteristics, growth, and yield of waterleaf (Talinum triangulare Jacq) showed that there was a significant increase in nitrogen content in cassava compost as compared to poultry manure-based compost.

Moreover, it can be seen in Table 10 that maize compost contains the highest amounts of all the important chemical nutrients followed by cassava compost and pineapple compost respectively. This means that all the compost will have an impact in amelioration compaction or and supporting plant growth and potential uses may vary according to end use.

Table 10: The pH and the percentage of carbon, nitrogen, phosphorus and potassium present in the compost applied

Compost	pH (H_2O)	%OC	%N	%P	%K
MC	7.4	30.5	2.5	0.91	3.1
CC	6.3	17.6	2.0	0.65	2.0
PC	6.2	14.4	1.9	0.58	1.1

Physical properties of the soil after soil compaction and compost application

Some physical properties of the experimental site after treatments application are presented in Table 11.

Table 11: Effect of treatments on physical properties of the soil

Level of compaction	Treatment	Porosity (%)	Bulk density (g cm^{-3})	HC (cm (min^{-1})	Moisture content (%)
Mild (Block 1)	Control	42.4	1.56	0.70	11.30
	CC	43.8	1.14	0.86	12.75
	MC	44.3	1.04	0.91	13.78
	PC	43.0	1.19	0.78	12.27
Lsd		0.86	0.12	0.17	0.78
Moderate (Block 2)	Control	43.2	1.42	1.40	12.40
	CC	42.2	1.18	0.80	12.39
	MC	43.1	1.10	0.85	13.11
	PC	41.1	1.22	0.75	11.72
Lsd		1.02	0.23	0.29	0.95
High (Block 3)	Control	44.5	1.34	1.31	13.90
	CC	41.6	1.21	0.76	11.84
	MC	42.8	1.16	0.81	11.97
	PC	40.3	1.25	0.71	11.11
Lsd		2.03	0.03	0.47	1.45
NTP	Control	43.1	1.47	0.80	14.50
	CC	44.3	1.02	1.01	14.18
	MC	44.9	0.96	1.17	15.23
	PC	43.7	1.09	1.03	13.13
Lsd		0.29	0.42	0.13	1.04

Treatment effects on Porosity

The highest porosity (%) for the mild compaction was 44.3 (%) that can be seen in the maize compost. The lowest porosity was the pineapple compost with the value of 43.0 (%). The porosity reported by maize compost (44.3%) shows that pore volume of soil lies within acceptable values to allow for aeration and gas exchange (Homes, 2013) compared to all other treatments.

There was an increased in the value of porosity for all treatments compared to the control treatment (42.4%). This means that compost addition had been able to create more pore space for adequate aeration in the soil

In the moderately compacted soil, the highest value for porosity was 43.1% and the least was 41.1%. Maize compost had the highest porosity and the least is pineapple compost. Although, maize compost was superior to other composts in ameliorating compaction, its value is significantly lesser than the control treatment's value.

As compaction elevates to the high level, the porosity values ranged from 40.3% to 42.8%. Maize compost recorded the highest porosity and the least was pineapple compost. This means that maize compost had the highest pore volume that allow for aeration and gas exchange amongst all the treatments.

The porosity in the no tractor passes section indicate a range of 43.7% to 44.9% after compost addition. The highest porosity was obtained on plots with maize compost with the least value from pineapple compost plots. The porosity recorded by maize compost (44.9 %) shows the highest pore volumes of soil that allow for aeration and gas exchange (Home Guides, 2013) amongst all treatments. There was a significant increase in the value of porosity for all treatments compared to the control treatment (43.1%). This means that compost addition had been able to create more pore space for adequate aeration in the soil.

In conclusion, maize compost recorded the highest value of porosity in all levels of compaction compared to all the composts. Maize compost superiorly had a higher porosity in NTP than the other levels of compaction.

Treatment effects on bulk density

In the mildly compaction level, bulk density value ranged between 1.04 g cm^{-3} and 1.19 g cm^{-3}. Pineapple compost plots recorded the highest bulk density value and the least was maize compost plot. The control treatment recorded 1.56 g cm^{-3} bulk density value which is greater than the bulk density value of all the treatment plots. This means that addition of compost had been able to ameliorate bulk density (NRC, 1993) and it will eventually results in proper root growth and development (Czyz et al., 2001).

As soil compaction elevate from mildly to moderately level of compaction, the bulk density values ranged from 1.10 g cm^{-3} to 1.22 g cm^{-3}. Pineapple compost plot maintained its top spot as the highest recorded bulk density value and the least was maize compost plot. All the treatment plots will increase germination, root movement plant grow rate and crop yield due to the lesser values of bulk density recorded by the individual treatment plots compared to 1.66 g cm^{-3} (Jones *et al*., 2012).

Soil compaction increased from moderate to the high level with 9 tractor passes. The bulk density values recorded ranged from 1.16 g cm^{-3} 1.25 g cm^{-3}. Amongst the compost treatments, the highest bulk density value was obtained in pineapple compost plots and lowest bulk density was from the maize compost plots. Again, the maize compost amendment significantly reduced high bulk density effect on the soil thereby improving the general condition of the soil for crop growth development and yield.

Bulk density in the no tractor passes level of compaction indicate a range of 0.96 g cm^{-3} to 1.09 g cm^{-3} after compost addition. Bulk density recorded by maize compost plot (0.96 g cm^{-3}) showed that there have been improvement in the soil by maintaining the soil structure and increases its nutrient-holding capacity (Sheoran et al., 2010). The bulk density for cassava, maize and pineapple compost plots in all the levels of compaction in Table 11 showed a reduction as compared to its control treatment (1.47 g cm^{-3}). The bulk density values showing significant difference means blocks were ameliorated by composts. The least bulk density was obtained on plots with maize compost with highest value coming from pineapple compost plots. Moreover, bulk density above 1.6 % g cm^{-3} impedes the general growth of crops and this is in contrarily to the values exhibited in Table 11 (Jones *et al.*, 2012).

In conclusion, maize compost plot recorded the lowest value of bulk density in all the compaction levels followed by cassava and pineapple compost plots respectively. Maize compost plot value for bulk density in no tractor pass level was absolutely the smallest compared to its values recorded in the other levels of compaction.

Treatment effects on hydraulic conductivity

In the mildly level of compaction the hydraulic conductivity values ranged between 0.78 min^{-1} and 0.91min^{-1}. The highest value for hydraulic conductivity was recorded by maize compost plot and the least value was pineapple compost plot. This means that the rate at which water moves in the soil is higher as compared to the other treatment plots. Again, the hydraulic conductivity value for all treatment is higher than the control treatment's value (0.70 min^{-1}) and this implies that addition had been able to increase the rate at which water moves in the soil.

In the moderately level of compaction, the hydraulic conductivity values ranged from 0.75 $\min^{-1}$ to 0.85 $\min^{-1}$. The highest value for the hydraulic conductivity was recorded by maize compost plot and the least value was recorded by pineapple compost plot. This implies that maize compost plot retained as the highest in the rate at which water moves in soil.

As compaction elevate from moderate to high level, the hydraulic conductivity value recorded in Table 11 ranged between 0.71 $\min^{-1}$ and 0.81 $\min^{-1}$. Maize compost plot recorded value for hydraulic conductivity is the highest amongst the other treatments plots indicating its superiority in at the rate at which water moves in the soil.

Lastly, the hydraulic conductivity value for no tractor pass ranged from 1.01 $\min^{-1}$ to 1.17 $\min^{-1}$. The highest value was from maize compost plot and the least was from pineapple compost. All compost treatment plot recorded values that are significantly higher than the control treatment (0.80 $\min^{-1}$). This indicate that compost addition had increased the rate at which fluid is transmitted through pore spaces and fractures in the soil thereby increasing the aeration and activities of microorganism in the soil, and this will eventually promote plant growth.

In conclusion, maize compost plot was able to increase the rate at which water moves in the soil in all the levels of compaction than the other compost plots.

Treatment effects on soil moisture contents

For the mildly compacted soil, the highest moisture contents was 13.78% and the least 12.27%. The highest coming from the maize compost plot and the least coming from the cassava compost plot. The increased in soil moisture contents by compost treatments plots compared to the control treatments (11.30%) was due to the addition of compost and other environmental factor. All the compost treatment plots value for soil moisture contents is within the range of 5% to 17% which is generally considered moderate and acceptable (Lewis, 2014) thereby promoting plant growth

As compaction elevate from mildly to moderately level, the values for soil moisture contents ranged from 11.72% to 13.11%. Maize compost plot recorded the highest value of soil moisture contents and the least was coming pineapple compost plot. The significantly increased in the soil moisture contents in maize compost plot signifies the increase in ability of the soil to hold water (U.S.D.A, 2016).

The highest value of soil moisture contents for highly compacted soil was 11.97%. The highest value was from maize compost plot. The highest value Again, the least value of soil moisture contents at this level of compaction was11.11% and this was from pineapple compost plot. Maize compost value for moisture contents wasn't higher than the control treatment's value at this level of compaction.

Lastly, soil moisture contents in the no tractor passes level indicate a range of 13.13% to 15.23% after compost addition. The highest soil moisture contents was obtained on plots with maize compost with the least value from pineapple compost. Moisture content within the range of 5% to 17% is generally considered moderate and acceptable (Lewis, 2014). Maize compost recorded 15.23% moisture contents that is within the acceptable range thereby promoting plant growth. The value for maize and pineapple compost on the high level of compaction plot also fall within the acceptable range (Lewis,

2014) and will increase soil ability to hold water, both directly and indirectly (USDA, 2016). In addition, all the compost on the various level of compaction reported acceptable range of moisture content. The moisture values showing significant difference means there will be available water for plant growth and development.

In conclusion, Maize compost plot recorded the highest value for soil moisture contents amongst the other compost treatment plots. Maize compost plots value for moisture contents was higher than the control treatment's value in all the levels of compaction with the exception of high level compaction.

Chemical properties of the soil after soil compaction and compost application

Some chemical properties of the soil as affected by the various composts applied are presented in Table 12

Table 12: Chemical properties of the soil after compaction and compost amendment

Level of compaction	Treatment	pH (H_2O)	CEC ($cmol_c$ kg^{-1})	O.C (%)	Tot.N (%)	Avai.P (µgp g^{-1})
	Control	5.70	5.60	1.20	0.20	16.30
Mild	CC	6.40	6.17	1.37	0.38	23.11
(Block1)	MC	6.42	6.23	1.40	0.42	23.53
	PC	6.34	6.12	1.39	0.30	22.45
Lsd		0.18	0.38	0.05	0.13	1.71
	Control	5.80	5.70	0.80	1.10	15.50
Moderate	CC	6.35	5.89	1.33	0.34	21.61
(Block 2)	MC	6.39	6.10	1.39	0.39	22.39
	PC	6.31	5.61	1.30	0.25	21.15
Lsd		0.24	0.09	0.21	0.42	2.02

	Control	5.90	5.30	1.10	0.10	14.60
High	CC	6.30	5.21	1.26	0.19	20.21
(Block 3)	MC	6.33	5.74	1.29	0.20	20.71
	PC	6.21	5.11	1.17	0.18	19.42
Lsd		0.21	0.19	0.11	0.06	3.17
	Control	6.20	6.00	0.90	0.20	13.40
NTP	CC	6.42	6.36	1.41	0.62	24.23
(Block 4)	MC	6.49	6.39	1.46	0.71	24.38
	PC	6.38	6.21	1.36	0.59	23.50
Lsd		0.13	0.15	0.29	0.38	7.01

Effect of treatment pH

The pH values at the mildly level of compaction ranged from 6.34 to 6.42. The highest value was from maize compost plot and the least value was pineapple compost plot. The compost treatment plot values for pH all exceeds the control treatment value and this indicate the impact of composts on a compacted soil. Again, the pH values for all the treatments value is above 4 and that will improve the absorption of calcium magnesium and phosphorus (PSS, 2014). Regardless of the tremendous work of all the composts, maize compost supersedes all the compost in improving the pH of the soil.

As compaction elevate from mild to moderate level, the ranged of values of soil pH was from 6.31 to 6.39. Again, maize and pineapple compost plots retained its highest and least value for pH respectively. The PH values recorded for all the treatment plots at this level was conducive for crops production since crops tolerate a soil of PH between 5.2 and 8.0 in other the optimum (Coleman et al., 2013).

The ranged of values for pH at the high level compaction presented in Table 12 was from 6.21 to 6.33. The highest recorded value of pH was maize compost plot and the least was from pineapple compost plot. The ideal pH range for most plants is between 5.5 and 7.0. (PSS, 2014). The pH values for all the treatments within the high level of compaction fall within the optimum range and are good for crops growth. Maize compost had increased pH compared to the control treatment.

Moreover, the pH values at this level of compaction (no tractor passes) range from 6.38 to 6.49. The highest was from maize compost plot and the lowest was from pineapple compost plot. There was a significant increase of pH values of all the treatment plots compared to the control treatments and this will be attributed to the addition of compost to those plots. Even though, all the treatments' value falls within the acceptable range of 5.5 to 7.0 (PSS, 2014), maize compost was superior in the increase of pH of the soil.

In conclusion, maize compost plot was superior in increasing the pH of the soil at all levels of compaction followed by cassava compost and pineapple compost respectively.

Effect of compaction and compost on CEC

At this level of compaction, the highest value for CEC was 6.23 $cmolcKg^{-1}$ and the least was 6.12 $cmolcKg^{-1}$. The highest and the least recorded CEC value was from maize and pineapple compost plot respectively. Maize compost plot improved the CEC tremendously compared to the other compost plot. The significant increase of CEC values of all treatments compared to the control treatment (5.60 c $molcKg^{-1}$) shows that there is more cation exchange capacity available to plants in other to balance, water and nutritive substance at a favorable temperature (Fredrick & Thompson, 1993).

The highest and the least values for CEC in the moderate level of compaction was 6.10 c molcKg^{-1} and 5.61 c molcKg^{-1} and this was from maize and pineapple compost plot respectively. Maize and cassava compost plot had higher CEC values compared to control treatment (5.70 c molcKg^{-1}). This shows that there is an improvement in CEC after the application of the irrespective composts. This increase of CEC by maize and cassava compost plots shows that the soil on the respective plots had the ability to provide essential plant nutrients including calcium, magnesium, and potassium (Rebecca and Kelly, 2003).

As compaction elevate from moderate to high level with nine tractor passes, the range of values for CEC was 5.11 cmolckg^{-1} to 5.74 cmolckg^{-1}. The highest value was from maize compost plot and the least value was pineapple compost plot. Maize compost plot recorded higher CEC value than the control treatment value (to 5.30 cmolckg^{-1}). This means that the end product of decomposed maize has the highest cation exchange capacity value amongst the other composts (Fredrick & Thompson, 1993).

The CEC values for no tractor passes level of compaction ranged from 6.21 cmolckg^{-1} to 6.39 cmolckg^{-1}. The highest CEC value was from maize compost plot and the least was from pineapple compost plot. The CEC values for all the compost treatment plots are higher than the control treatment plot (6.00 cmolckg^{-1}). Regardless of the decomposition maize, cassava and pineapple to release high cation exchange capacity (Fredrick & Thompson, 1993), maize compost was superior amongst the other composts.

In conclusion, the CEC value of maize compost increases as the level of compaction decreases. Again, maize compost had higher value of CEC in all levels compared to the control treatment.

Effect of compaction and compost on organic carbon contents

The organic carbon within the mild section has a range of 1.37% to 1.40% after compost application. The higher organic carbon contents was obtained on plot with maize compost with the least value coming from cassava compost plot. The organic carbon contents recorded by all the compost fall within the acceptable range of 1% to 6% (SARE, 2013) and this will help give soil its water-retention capacity, structure and fertility (Schwartz, 2014).

In the moderately compacted block, maize compost had the highest organic carbon of 1.39% with pineapple compost recording the least organic carbon contents of 1.30%. There was an increase in organic carbon contents for all treatments. This better-quality organic carbon could be credited to the direct enhancement of the soil compost. Regardless of the increase of organic carbon contents by all compost treatment plot, maize compost is superior to give the soil improved ability to retain water, improve structure and fertility (Schwartz, 2014).

In the highly compacted block, maize compost resulted in the highest the highest organic carbon of 1.29% with pineapple compost resulting in the least organic carbon of 1.17%. There was an increase in organic carbon for all treatments after compost application. Soils on the compost treatment plot at this level of compaction fall within the acceptable range of 1% to 6% (SARE, 2013) and therefor enough to relieve soil compaction (Batey, 2009).

The organic carbon contents within the no-tractor pass section ranged from 1.36% to 1.46% after compost application. The highest organic carbon was obtained on plot with maize compost with least value coming from pineapple compost plot. The control treatment value of organic carbon contents (0.90%) does not fall within the acceptable range of 1% to 6% (SARE, 2013) but it was later improved by the addition of composts (maize, cassava and pineapple composts) as stipulated by the range above. This will eventually get rid of soil compaction (Batey, 2009) and improves water retention capacity and fertility of the soil (Schwartz, 2014).

In conclusion, all the compost treatments were able to increase the organic carbon content of the soil at all levels of compaction. The values of organic carbon recorded by all the compost treatment plots at no tractor pass level were greater than the respective values at the other levels of compaction.

Effects of compaction and composts on soil total nitrogen contents

The total nitrogen contents of soil in the mild compacted section indicated a range 0.30% to 0.42% after compost application. The highest nitrogen content was obtained on plot with maize complot with the least coming from pineapple compost plot. Pineapple compost plot which is the least recorded soil total nitrogen was able to increase the total nitrogen of soil as compared to the control treatment (0.20%). It means that total nitrogen of all plots applied with compost had increased significantly and will support the leaf of the plant to grow well (Sangina and Woomer, 2009).

As compaction elevate from mild to moderate, the soil total nitrogen ranged from 0.25% to 0.39%. Maize compost plot had the highest nitrogen content and the least was pineapple compost plot. At this level of compaction the control treatment value (1.10%) for soil total nitrogen contents is higher than the individual values of compost treatment plot. This shows that the soil after compost application wouldn't be able enough to regain more nitrogen.

Maize compost had the highest soil total nitrogen contents of 0.20% within the high level of compaction whilst pineapple compost plot has the least nitrogen contents of 0.18%. The values recorded by the individual treatment is higher when compared to the control treatment (0.10%). This shows that, after the compost application the soil was able to regain more nitrogen content in high level of compaction.

Total nitrogen within the no-tractor passes section indicate a range of 0.59% to 0.71%. However, the highest was maize compost plot and the lowest was from pineapple compost plot. There was a significant increase of soil total nitrogen on all the compost treatment plots when compared to the control treatment value (0.20%). This means that soil will be able to support plant growth, plant food processing and the creation of Chlorophyll (Smith et al., 2011). Moreover, maize compost will support plant growth more than the other compost treatment plots.

In conclusion, all compost treatment plots had higher value of soil total nitrogen compared to the control treatment plot in all level of compaction with the exception of moderate level (6 tractor passes). Maize compost plot had higher value on total nitrogen contents than the other compost treatment plot at all level of compaction. The value of nitrogen contents recorded by the individual compost plots at no tractor pass was higher than its respective values at the other level of compaction.

Effects of compaction and composts on available phosphorus

Available phosphorus in mildly compacted section ranged from 22.45 µgp g^{-1} to 23.53 µgp g^{-1}. The highest available phosphorus content was obtained on plot with maize compost with the least value from pineapple compost plot. All the compost treatment plot value for available phosphorus is higher than the control treatment plot's value, signifying improvement in available phosphorus for soil on the compost treatment plot. This major increase in available phosphorus content will help flowering process and increase grain yields (Sangina & Woomer, 2009).

As compaction elevate from mildly to moderately level, the range of values for available phosphorus is 21.15 µgp g^{-1} to 22.39 µgp g^{-1}. The least value of available phosphorus is from pineapple compost plot and is higher than the control treatment plot (15.5 µgp g^{-1}). This means that, there was an improvement in available phosphorus for all the compost treatment plot. Again, the values for all the compost treatment plot fall within the acceptable range for available phosphorus content for optimal growth of crops which is between 10 µgp g^{-1} to 40 µgp g^{-1} (Sangina & Woomer, 2009).

In the highly compacted soil, the range of values for available phosphorus is between 19.42 µgp g^{-1} to 20.71 µgp g^{-1}. Maize compost plot recorded the highest available phosphorus and the least was from pineapple compost plot. The values for available phosphorus content recorded in Table 12 specify that the values for all compost treatment plots in this level of compaction were lower when compared to its respective values in moderate level of compaction. This is attributed to the high nature of compaction at this level (9 tractor passes). Regardless of lower values for available phosphorus, there was an increase of available phosphorus by compost treatment plots compared to the control treatment (14.60 µgp g $^{-1}$).

Lastly, in the no-tractor pass treatments, maize compost had the highest available phosphorus of 24.38 µgp g $^{-1}$ with pineapple compost showing the lowest available phosphorus of 23.50 µgp g $^{-1}$. Even though, the control treatment value of 13.40 µgp g $^{-1}$ falls within the acceptable range as reported by (Sangina & Woomer, 2009) compost application generally increase the available phosphorus contents. This means that there was an enough phosphorus contents capable of speeding flowering process and increasing grain size (Sangina & Woomer, 2009).

In conclusion, the available phosphorus contents decreases as the level of compaction increases. There was a significant increase of available phosphorus contents by all compost treatment plot compared to the control treatment plot at all the levels of compaction.

The grain yield of maize for the various compacted area with composts

Harvested maize from the various compacted area with compost were weighed and the result is shown in Table 13.

Table 13: Maize yield on the various compacted plots with compost

Compost	NTP(kg/ha)	Mild(kg/ha)	moderate(kg/ha)	High(kg/ha)
Maize	8.24	7.92	5.15	3.52
Cassava	6.31	4.28	4.05	2.86
Pineapple	5.45	3.40	3.60	2.72
Total	20.00	15.60	12.80	9.10

Maize compost as an amendment resulted in 8.24 kg/ha of maize yield which was the highest in NTP followed by cassava compost (6.31 kg/ha) and pineapple compost (5.45 kg/ha). In all the compaction levels, maize compost remained the treatment amongst the composts with the highest impact on maize yield. These results are consistent regardless of soil compaction level (Table 13). However, in terms of yield out puts from the various levels of soil compaction, the yields of maize recorded have been 20.0, 15.0, 12.8 and 9.1 kg/ha maize yields for NTP, mild, moderate and high respectively (Table 13).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview

This chapter provides a summary of the work and draws conclusions based on the data analysis and provides recommendations for other researchers.

Summary

Data was gathered and analysed to detect the type of compost that would have the greatest effect on reducing soil compaction based on physico-chemical property of the soil. Data gathered was also used to determine how effective these composts were able to remediate compacted soil.

Soil compaction was noted to have adverse effect on maize yield. Different levels of compaction were prepared and different composts were applied with the focus of reducing the impact of compaction on maize yield. Data on the physical properties of the soil before soil compaction and compost application were determined to know the initial stage of the soil (whether it will support plant growth or not), and the effect the compost application will have on the soil after soil had been compacted and compost applied. It was observed that the values obtained for bulk density and porosity indicated soil compaction with greater compaction resulting in less pore space, respectively. This means that soil compaction has a negative impact on the soil and some of them are the decrease in infiltration rate, reduction in root growth and penetration resistance. Data on physical properties of the soil after compaction shows that composts application improved the physical properties of the soil since the values for bulk density were significantly reduced. This means that the compost types were effective in ameliorating soil compaction

Amongst the compost materials, maize compost consistently improved compacted soils.

Conclusions

The study revealed the impact of different types of compost and various compaction levels as well as their interaction on some physico-chemical properties, growth and yield of maize. Machinery can cause some level of compaction, tractors, combine harvesters and other heavy transport equipment should not be used to work on clay soils because they increase the soil compaction; the situation is even worsened when the soil is wet (Chowdhury & Hoque, 2013). This is because when water content of the soil is low, the soil becomes stiff and difficult to compact (Duttmann *et al*., 2014) and as the soil water increases, the thickness around the soil particles also increases, resulting in cohesion among the particles and further allowing them to slide over one another resulting in a high degree of compaction (Sandras, 2009).

Total porosity, which refers to the amount of pore space accessible in the soil for air and water flow, is inversely related to soil bulk density (Carter & Ball, 1993). Hence, high bulk density reduces aeration and increase penetration resistance and low bulk density increase aeration. This is because high bulk density makes the soil to be compacted and a compacted soil reduce infiltration.

In the study, it was revealed that the block with the highest number of passes 9, had high soil bulk density, decreased aeration, reduced porosity. It was also revealed that Block 2 (moderate) had the second highest soil bulk density, decreased aeration, reduced porosity and limited oxygen. In contrast, Block 2 had higher crop yield than Block 3. Block 4 (NTP) had low soil bulk density because there wasn't a tractor pass which will have exerted more force on the soil to have been compacted. Since Block 4 had low bulk density, there will be high aeration, increased porosity and high oxygen content for respiration by maize, which resulted in good yield. Block 1 (mild) also had a lesser porosity as compared to Block 4, however it was better than Block 3 and 2. This means that the higher the tractor passes (level of compaction), the higher the bulk density and the higher the bulk density the lower the crop yield.

Data gathered from the various blocks indicate that maize compost (MC), cassava compost (CC), pineapple compost (PC) were effective in ameliorating soil compaction because of improved soil conditions such as aeration, porosity and nutrients that are accessible for crop growth but maize compost (MC) is highly recommendable.

Maize compost was most efficient in ameliorating compaction as compared to cassava compost and pineapple compost. Aeration, porosity and nutrient contents for maize compost was the highest in all the levels of compaction.

Lastly, maize Compost (MC) obtained the highest yield followed by CC and PC in that order. Block 4 recorded the highest yield followed by block 1, block 2 and block 3 in that order. Therefore, addition of compost increases the growth rate and yield of maize.

Recommendation

High bulk density soils as a result of increased compaction should be amended with maize compost to reduce compaction and improve the physico-chemical properties as has been demonstrated in this study. Soil amendments, especially with MC should therefore be applied on the soil to enhance crop growth and yield. Though, compost reduces compaction, its application should be done before crops are grown to allow for full decomposition to break up the compacted layers and allow increased access to the manure for better growth and yield.

To measure the crop yield, it is better considering total grain yield from each plot to ascertain the appropriate and effective measure with regards to the various composts.

REFERENCES

Abdollahi, L., Schjonning, P., Elmholt, S., & Munkholm, L. J. (2014). The effects of organic matter application and intensive tillage and traffic on soil structure formation and stability. *Soil and Tillage Research, 136,* 28-37.

Abdullai, S., Nkegbe, P. K., & Donkoh, S. A. (2013). Technical efficiency of maize production in Northern Ghana. *African Journal of Agricultural Research, 8*(43), 5251-5259.

Atkinson, J. (2014). Compaction Purpose and Processes. Retrieved from http://environment.uwe.ac.uk/geocal

Adesigbin, A. J., & Fasinmirin, J. T. (2012). Soil Physical Properties and Hydraulic Conductivity of Compacted Sandy Clay Loam Planted with Maize (Zea mays) Proceedings of the Environmental Management Conference. *University of Agriculture, Abeokuta, Nigeria*, 2.

Adler, O. P., Totsche, K. U., & Novak, J. M. (2015). Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant and soil, 324*(1-2), 1-30.

Agren, I. G., & Franklin, O. (2003). Root: shoot ratios, optimization and nitrogen productivity. *Annals of Botany* 92:795-800.

Alexandria, V. (1994). *Compost Facility Operating Guide.* The Composting Council.

Alleto, L., Coquet, Y., & Roger-Estrade, J. (2010). Two-dimensional spatial variation of soil physical properties in two tillage systems. *Soil use and management, 26* (4), 432-444.

Ampoorter, E., Van Nevel, L., De Vos, B., Henry, M., & Verheyen, K. (2010). Assessing the effects of initial soil characteristics, machine mass and traffic intensity on forest soil compaction. *Forest Ecology and Management, 260*(10), 1664-1676.

Andrade, A., Wolfe, D. W., & Fereres, E. (1993). Leaf expansion, photosynthesis and water relations of sunflower plants grown on compacted soil. *Plant Soil, 149*: 175-184.

Asady, G.W., Smucker, J. M., & Adams, M. W. (1985). Seedling test for the quantitative measurement of roots tolerances to compacted soil. *Crop science 25*:802-806.

Asli, S., & Neumann, P. M. (2009). Colloidal suspension of clay or titanium dioxide nanoparticles can inhibit leaf growth and transpiration via physical effects on root water transport, *Plant, cell & environment, 32*(5), 577-584.

Atwell, B. J. (1990). Response of roots to mechanical impedance. *Environmentaland Experimental Botany 33*:27-40.

Bajzalj, B., Richards, K. S, Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation, *Nature Climate Change, 4*(10), 924.

Baldantoni, D., Leone, A. Iovieno, P., Morra, L., Zaccardelli, M., & Alfani, A. (2010). Totsl and available soil trace element concentrations in two Mediterranean agricultural systems treated with municipal waste compost or conventional mineral fertilizers, *Chemosphere, 80*(9), 1006-1013.

Batey, T. (2009). Soil compaction and soil management -a review. *Soil use and management*, *25*(4), 335-345.

Bear, J., & Verruijt, A. (2012). *Modeling groundwater flow and pollution* (vol. 2): Springer Science & Business Media.

Bell, C., & Donnelly, L.J. (2014). *Mining and its Impact on the Environment:* CRC Press.

Berisso, F. E., Schjønning, P., Keller, T., Lamandé, M., Etana, A., de Jonge, L.W., & Forkman, J. (2012). Persistent effects of subsoil compaction on pore size distribution and gas transport in loamy soil. *Soil and Tillage Research*, *122*, 42-51.

Berthrong, S. T., Jobbagy, E. G., & Jackson, R. B. (2009). A global meta-analysis of soil exchangeable cations, pH, carbon and nitrogen with afforestation. *Ecological Applications*, *19*(8), 2228-2241.

Blanco-Canqui, H., & Lal, R. (2019). Crop residue removal impacts on soil productivity and environmental quality. *Critical review in plants science28*(3),139-163.

Botta, G. F., Becerra, A. T., & Tourn, F. B. (2009). Effect of the number of tractor passes on soil rut depth and compaction in two tillage regimes. *Soil and Tillage Research*, *103*(2), 381-386.

Bouajila, K., & Sanaa, M. (2011). Effects of organic amendments on soil physico-chemical and biological properties. *J. Mater. Environ Sci, 2(1),* 485-490.

Bouycocos, J. V. (1963). Hydroacoustic oscillator-amplifier: Google Patents.

Bowden, C. L. (2006). Effects of organic soil amendments on soil physicochemical and crop physiological properties of field grown corn (*Zea mays*) and Soyabean (*Glycine Max*). Thesis submitted to the Facultyof the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the Degree of Master of Science in Crop and Soil Environmental Sciences. 12p.

Bowe, A. (2011). *High-Impact, Low-carbon Gardening: 1001 Ways to Garden Sustainability:* Timber Press.

Bremner, J. M. & Mulvaney, C.S. (1982). Total nitrogen. In: page, A. L., Miller, R. H. & Keeney, D. R. (eds.). *Methods of Soil Analysis*. Part 2. Chemical and microbiological properties. American Society of Agronomy and Soil Science Society of America, Madison Wisconsin Inc.pp. 593-624.

Burger, J., Graves, D., Angel, P., Davis, V., & Zipper, C. (2017). The forestryeclamation approach. *In: Adams, Mary Beth, ed. The Forestry Reclamation Approach: guide to successful reforestation of mined lands. Gen. Tech. Rep NRS-169. Newtown Square, PA: US Department of Agriculture, Forest Series, Northern Research Station: 2-1-2-8.*, 1-8.

Burgess, C. P., Chapman, R., Singleton, P. L., & Thom, E. R. (1998). Effects of livestock treading and mechanical loosening of soil. *Proceedings of the New Zealand Society of Soil Science*, Gisborne. Pp. 99-100

Buttery, B. R., Tan, C. S., Drury, C. F., Park, S.J., Armstron, R. J., & Park, K. Y. (1998). The effects of soil compaction, soil moisture and soil type on growth and nodulation of soyabean and common bean. *Can.J.Plant Sci*. 78:571-576.

Cahill, J. F. Jr. (1999). Fertilization effects on interactions between above and below ground competition in an old field. *Ecology 80*:466-480.

Cahill, J. F. Jr. (2002). Interactions between root and shoot competition vary among species. *Oikos 99*:101-112.

Cambi, M., Certini, G., Neri, F., & Marchi, E. (2015). The impact of heavy traffic on the forest soils: a review. *Forest Ecology and Management, 338*, 124138.

Campbell, D. J., & Henshall, J. K. (1991). *Bulk density.p*. 329-366. In Smith K. A. & Mullins C. E. (eds.) Soil analysis. Physical methods. Marcel Dekker, New York.

Campbell, D. J., & O'Sullivan, M. F. (1991). The cone penetrometer in relation to trafficability, compaction and tillage. In: Smith, K. A. and Mullins, C. E. (Eds.), *Soil analysis. Physical methods*. Marcel Dekker, New York, USA, pp. 399-430.

Carter, M. R., & Ball, B. C. (1993). Soil porosity. In: Carter, M. R. (Ed.), *Soil sampling methods of soil analysis*. Lewis Publishers, pp. 581-588.

Cassel, D.K. (1982). Tillage effects on soil bulk density and mechanical impedance. In: Unger, P. W. & Van Doren, D. M. (Eds.). *Predicting tillage effects on soil physical properties and processes*. ASA-Soil Science Society of America, Madison, USA, pp. 45-67.

Cavaliery, K. M. V., da Silva, A. P., Tormena, C. A., Leão, T.P., Dexter, A.R., & Håkansson, I. (2009). Long-term effects of no-tillage on dynamic soil physical properties in a Rhodic Ferrasol in Paraná, Brazil. *Soil and Tillage Research*, *103* (1), 158-164.

Chen, G., & Weil, R. R. (2009). Root growth and yield of maize as affected by soil compacion and cover crops. *Soil and Tillage Research 117*, 17-27.

Chen, Y., Tessier, S., & Rouffignat, J. (1998). Soil bulk density estimation for tillage systems and soil textures. *Trans.ASAE*, *41*:1601-1610.

Chen, Day, S. D. Wick, A. F., & McGuire, K. J. (2014). Influence of urban land development and subsequent soil rehabilitation on soil aggregates, carbon, and hydraulic conductivity, *Science of the Total Environment*, *494*, 329 336.

Chowdhury, M., & Hoque, R (2013). Shear strength properties of compacted expensive soils. Faculty of Graduate Studies and Research, University of Regina.

Coder, K. D., (2000). *Soil compaction and trees: Causes, symptoms and effects.* University of Georgia School of Forest Resources, Athens, GA., July 2000, pp: 1-37.

Coleman, D. C., Callaham, M. A., & Crossley Jr, D. A. (2017). *Fundamentals of soil ecology:* Academic Press.

Counsel, M. A. T. G. (2016). The effects of climatic variable and crop yield and variability in Ghana. *Russian Journal of Agricultural and Socio-Economic Sciences*, *10*(10).

Cresswell, H. P., & Kirkegaard, J. A. (1995). Subsoil amelioration by plant roots- the process and the evidence. *Aust. J. Soil Res. 33*, 221-239.

Crush, J. R., & Thom, E. R. (2011). Review: The effects of soil compaction on root penetration, pasture growth and persistence. *Pasture Persistence Grassland Research and Practice Series, 15:* 73-78.

Czyz, E. A., Tomaszewski, J., & Dexter, A. R. (2001). Response of spring barley to changes of compaction and aeration of sandy soil under model conditions. *International agro-physics 15*:89-105 D.C., U.S.A. June.

Défossez, P., Richard, G., Boizard, H., & O'Sullivan, M. F. (2003). Modeling change in soil compaction due to agricultural traffic as function of soil water content. *Geoderma 116*:89-105.

DeJong-Hughes, J. (2009). *Tires, traction and compaction*. *Report, University of Minnesota Extension.*

Domzal, H., & Hodara, J. (1991). Physical properties of three soils compacted by machine wheels during field operations. *Soil Till*. Res. *19*: 227-236.

Drewry, J.J., Cameron, K.C., & Buchan, G.D. (2008). Pasture yield and soil physical property responses to soil compaction from treading and grazinga review. *Soil Research*, *46*(3), 237-256.

Duttmann, R., Schwanebeck, M., Nolde, M., & Horn, R. (2014). *Predicting soil compaction risks related to field traffic during silage maize harvest. Soil Science Society of America Journal, 78*(2), 408-421.

Edith, A. (2018) Composting in North-East Ghana. Retrieved from https://sabab- lou.de/en/composting

EPA (United States Environmental Protection Agency) (2007). The use of Soil Amendments for Remediation, Revitalization, and Reuse. Solid Waste and Emergency Response (5203P). EPA/National Service Center for Environmental Publications. 52p.

Etana, A. (1995). Compaction effects of mechanical stress on some Swedish arable soils. PhD Thesis, Swedish University of Agricultural Sciences, Uppsala.

Floudas, D., Binder, M., Riley, R., Barry, K., Blanchette, R. A., Henrissat, B., & Yadav, J. S. (2012). The Paleozoic origin of enzymatic lignin decomposition reconstructed from 31 fungal genomes. *Science, 336*(6089), 1715-1719.

Franzluebbers, A. J., & Stuedemann, J. A. (2008). Early response of soil organicfractions to tillage and integrated crop-livestock production. *Soil Science Society of America Journal, 72*(3), 613-625.

Fredrick, L., & Thompson, M. (1993). Oxford University press New York. NY

Gill, K. S., & Aulakii, B. S. (1990). Wheat yield and soil bulk density response to some tillage systems on an Oxisol. *Soil Tillage Res*. 18: 37-45 Glab, 2007.

Grassini, P., Thorburn, J., Burr, C., & Cassman, K.G. (2011). High-yield irrigated maize in the Western US Corn Belt: I. On-farm yield, yield potential, and impact of agronomic practices. *Field crop research, 120(1)* 142-150.

Gruhn, P., Golleti, F., & Yudelman, M. (2000). *Integrated Nutrient Management, Soil Fertility and Sustainable Agriculture:* Current Issues and Future Challenges. Washington D.C.

Grzesiak, M. T. (2009). Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. *Plant Root 3*: 10-16. Doi:10.3117/Plant Root.3.10.

Günal, H., Korucu, T., Birkas, M., Ozgoz, E., & Halbac-Cotoara-Zamir, R. (2015). Threats to sustainability of soil functions in Central and Southeast Europe. *Sustainability. 7(2)* 2161-2188.

Hadas, A. (1994). *Soil compacion caused by high axle loads. Review of concept and experimental data. Soil Tillage Research 28* (2-3): 253-276.

Hakansson, I., & Lipiec, J. (2000). A review of usefulness of relative bulk density values in studies of soil structure and compaction. *Soil and Tillage Research 53* (2): 71-85

Hamza, M. A., Al-Adawi, S. S., & Al-Hinai, K. A. (2011). Effect of combined soil water and external load on soil compaction. *Soil Research, 49*(2), 135-142.

Hatley, D., Wiltshire, J., Basford, B., Royale, S., Buckley, D., & Johnson, P. (2005). Soil compaction and potato crops. Research review, 260.

Haug, R. T., & Ann, A. (1994). *Compost Engineering Principles and Practices*, Science Publishers, First Edition.

Hempson, G. P., Archibald, S., Bond, W. J., Ellis, R. P., Grant, C. C., Kruger, F. J., & Peel, M. J. S. (2015). Ecology of grazing lawns in Africa. *Biological Review, 90*(3), 979-994.

Hillel, D. (2012). *Soil and water: physical principles and processes:* Elsevier.

Home Guide. (2013). How to make soil more porous. Retrieved from www.homeguides.stgate.com>more-soil

Houlbrooke, D. J. (1996). Subsoiling and soil compaction effects on soil physical properties and pasure response. Unpublished MSc thesis, University of Waikato, 15 p.

Iren, O. B., Akpan, F. J., & Ediene, V. F. (2015). Influence of cassava peels and poultry manure-based compost on soil properties, growth and yield of waterleaf (Talinum triangulare Jacq) in an ultisol of south-eastern Nigeria. *Journal of soil and environment management, 6*, 187-194.

Ishag, M., Hassan, A., Saeed, M., Ibrahim, M., & Lal, R. (2001). Subsoil compacion effecs on crops in Punjab, Pakisan. I. Soil physical properties and crop yield. *Soil Tillage Research* 57-65.

Janssen, M., & Lenartz, B. (2009). Water losses through paddy bunds: methods, experimental data, and simulation studies. *Journal of hydrology 369* (1-2), 142-153.

Jéan, P. (2003). Maize Production. Department of Agriculture and obtainable from Resouce Centre Directorate Agricultural Information Services. Pp 1-34.

Johkan, M., Shoji, K., Goto, F., Hashida, S., & Yoshihara, T. (2010). Blue light emitting diode light irradiation of seedlings improves seedlings quality and growth after transplanting in red leaf lettuce. *HortScience, 45*(12), 1809-1814.

Jones, D. L., Rousk, J., Edwards-Jones, G., DeLuca, T. H., & Murphy, D. V. (2012). Biochar-mediated changes in soil quality and plant growth in a three-year field trial. *Soil Bioligy and Biochemistry, 45,* 113-124.

Jordan, A., Zavala, L. M., & Gil, J. (2010). Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena, 81*(1), 77-85.

Jurry, W. A., & Stolzy, L. H. (2018). Soil physics: *Handbook of Soils and Climate in Agriculture* (pp. 131-158): CRC Press.

Karagiannis, G. A. Altinas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., & Weil, T. (2011). Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions. *IEEE communications surveys & tutorials, 13* (4) 584-616.

Kemp, P., Sear, D., Collins, A., Naden, P., & Jones, I. (2011). The impacts of fine sediments on riverine fish. *Hydrological Processes, 2* (11) 1800-1821.

Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M.N., Rayorath, P., Hodges, D. M., & Prithiviraj, B. (2009). Seaweed extracts as bio-stimulants of plant growth and development. *Journal of Plant Growth. Regulation, 28*(4), 386-399.

Kimetu, J. M., Mugendi, D. N., Palm, C. A., Mutuo, P. K., Gachengo, C. N., Nandwa, S., & Kungu, J. B. (2004). *Nitrogen fertilizer equivalency values for different organic materials based on maize performance at Kabete, Kenya*. Academy of Science Publishers, Nairobi, Kenya. pp. 207223.

Kingwell, R., & Fuchsbichhsler, A. (2011). The whole-farm benefit of controlled traffic farming: An Australian appraisal. *Agricultural Systems*, *104*(7), 513-521.

Koch, H., Heuer, H., Tomanova, O., & Marlander, B. (2008). Cumulative effect of annually repeated passes of heavy agricultural machinery on soil structural properties and sugar beet yield under two tillage systems. *Soil and Tillage Research*, *101*(1-2), 69-77.

Kurtz, L. (2019). *How to Prepare Garden Compost*. City of Aurora in Colorado.

Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. *Journal of Soil and Water Conservation*, *70*(3), 71-77.

Lai, L., & Kumar, S. (2020). A global meta-analysis of livestock grazing impacts on soil properties. PLos ONE 15(8):e0236638. Retrieved from https://jornals.plos.org/plosone/art

Lamande, M., & Schjonning, P. (2011). Transmission of vertical stress in a real soil profile. Part II: Effect of tyre size, inflation pressure and wheel load. *Soil and Tillage Research*, *114*(2), 71-77.

Lampurlanes, J., & Cantero-Martinez, C. (2003). Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Agronomy Journal 95*:526-536.

Landon, J. R. (2014). *Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics*: Routledge.

Law-Ogbomo, K. E., & Law-Ogbomo, J. E. (2009). The performance of Zea mays as influenced by NPK Fertilizer application. *Not Sci. Biol. 1*(1): 59-62.

Lewis, J. (2014). Percentage of moisture content that support plant growth. Retrieved from https://www.hunker.com>at-what-percentage

Lipiec, J., & Hatano, R. (2003). Quantification of compaction effects on soil physical properties and crop growth. *Geoderma, 116*: 107-136.

Lorenz, K., & Lal, R. (2005). The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. *Advances in Agronomy 88*: 35-66.

Lowery, B., & Schuler, R. T. (1991). Temporal effects of subsoil compaction on soil strength and plant growth. *Soil Science Society of America Journal 55*: 216-223.

Mackay, A. D., Gillingham, A., Smih, C., Budding, P., Phillips, P., Clarke-Hill, W., & Johnstone, P. (2010). Evaluation of the effects of grass species, irrigation, nitrogen fertiliser application and soil compaction on the response of modern dairy pastures to phosphorus fertiliser. *Proceedings of the New Zealand Grassland Association 72:* 153-158.

McCauley, A., Jones, C., & Jacobsen, J. (2009). Soil pH and organic matter. *Nutrient management module 8,* 1-12.

McCormack, S. A., Ostle, N., Bardgett, R. D., Hopkins, D. W., & Vanbergen, A. J. (2013). Biochar in bioenergy cropping systems: impacts on soil faunal communities and linked processes. *GCB Bioenergy, ecosystem 5*(2), 81 95.

McKenzie, R. H. (2010). Agricultural soil compaction: causes and management. Agric-facts. Practical information for Alberta's Agriculture Industry. Agdex 510-110.

Meehan, C. L., Cacciola, D. V., Tehrani, F. S., & Baker III, W. J. (2017). Assessing soil compaction using continuous compaction control and location-specific *in situ* tests. *Automation in Construction, 73,* 31-44.

Moore, G. (1998). *Soil Guide: a handbook for understanding and managing agricultural soils.* Department of Agriculture, Western Australia Bulletin No. 4343.

Muhammad, R., Gul, D. K., Muhammed, H., & Shahid, A. (2012). Impact of soil compaction on root length and yield of corn (Zea mays) under irrigated Condition. *Middle-East Journal of Scientific Research 11* (3): 382-385.

Mujdeci, M., Issildar, A. A., Uygur, V., Alaboz, P., Unlu, H., & Senol, H. (2017). Cooperative effects of field traffic and organic matter treatments on some compaction-related soil properties. *Soil Earth, 8*(1), 189-198.

Mukherjee, A., Lal, R., & Zimmerman, A. R. (2014). Effects of biochar and other amendments on the physical properties and greenhouse gas emissions of an artificially graded soil. *Science of the Total Environment, 487*, 26-36.

Mutegi, E. M., Kung'u, J. B., Mucheru-Muna, F., & Mugendi, D. (2012). Consequences of organic-mineral N soil fertility amendments of nitrogen uptake and maize grain yield in the smallgolder farms of

Meru Souh disrict, Kenya. *Sky Jounal of Soil Science and EnvironmentalManagement 1*(1): 9-14.

Nawaz, M. F., Bourrie, G., & Trolard, F. (2013). Soil compaction impact and modelling. A review. *Agronomy for Sustainable Development, 33*(2), 291 309.

NRC (National Research Council) (1993). Soil and water quality: An agenda for agriculture. Washington, DC: National Academy Press (Publishers).

Obuobie, E., & Barry, B. (2010). Groundwater in sub-Saharan Africa: Implications for food security and livelihoods. *Ghana Country Status on Groundwater, final report.*

Ocloo, C. Y. (2011). The response of roots and biomass yield of soyabean and maize seedlings to different levels of soil compaction. A thesis submitted to the Department of Crop and Soil Sciences, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 170p.

OkeChukwu, R., Ntawuruhunga, P., Dziedzeoave, N., Manu-Aduening, J., ISTRC, A.B., Adu-Kwarteng, E., & Darko, M.N. (2013). Competitiveness of Root Crops for Accelerating Africa's Economic Growth, 12th TriennialSymposium of International Society for Tropical Root Crops Africa Branch (ISTRCAB), Accra, Ghana, 30 September-5 October 2013.

Oldeman, I., R., Hakkeling, R. T. A., & Sombroek, W. G. (1991). World map of status of human induced soil, an explanatory note. ISRIC. Wageningen, Netherlands/UNEP, Nairobi, Kenya. 34.

Oslen, S. R., & Sommers, L.E. (1982). Methods of Soil Analysis, Part 2. Agron. Monogr. 9. ASA and SSA, Madison, WI. *Phosphorus.* P 403-430.

Oussible, M., Crookstan, R. K., & Larson, W. E. (1992). Subsurface compaction reduces the root and shoot growth and grain yield of wheat. *Agronomy Journal, 84*: 34-38.

Pandey, V. C., & Singh, N. (2010). Impact of fly ash incorporation in soil systems. *Agriculture, Ecosystem & Environment, 136* (1-2) 16-27.

Park, J. H., Lamb, D., Paneerselvam, P., Choppala, G., Bolan, N., & Chung, J. (2011). Role of organic amendments on enhanced bioremediation of heavy metal (loid) contaminated soils. *Journal of hazardous materials, 185*(2), 549-574.

Passioura, J. B. (2002). Soil compactions and growth. *Plant cell and Environ, 25:* 311-318.

Pengthamkeerati, P., Motavalli, P. P., & Kremer, R. J. (2011). Soil microbial activity and functional diversity changed by compaction, poultry litter and cropping in a claypan soil. *Applied Soil Ecology, 48*(1) 71-80.

PSS, (2014). pH for the Garden-The University of Vermont. Retrieved from http://www.pss/urm-edu-ppp-pubs

Pleasant, B. (2012). *How to Make Compost***.** Mother Earth News Ogden Publications, Inc**.** 1503 SW 42nd St., Topeka, Kansas.

Quagraine, K.A. (2014). West African monsoon (WAM) jump and its implication for rain-fed agriculture in the transition and coastal savannah agro ecological zones of Ghana. University of Cape Coast.

Rab, M. A. (2004). Recovery of soil physical properties from compaction and soil profile disturbance caused by logging of native forest in Victorian Central Highlands, Australia. *Forest Ecology and Management 191*(1): 392-340.

Radford, B. J., & Thornton, C. M. (2011). Effects of 27 years of reduced tillage practices on soil properties and crop performance in the semi-arid subtropics of Australia. *International Journal of Energy Environment and Economics, 19*(6), 565-595.

Rahman, H. M., Kawai, S., Alam, S., Hoque, S., Tanaka, A., & Ito, M. (1999). Effect of Soil Compaction on Plant Growth in an Andisol. *Jpn. J. Trop. Agr. 43*(3) 129-135.

Raza, W., Yousaf, S., Niaz, A., Rasheed, M. K., & Haussain, I. (2005). Subsoil compaction effects on soil properties, nutrient uptake and yield of maize fodder (Zea mays L.). *Pak. J. Bot., 37*(2): 933-940.

Reich, P. B. (2002). Root: shoot relationships: Opimality in acclimation and adaption or the "Emperor's new clothes"?. Third edition revised and expanded. Yoav, W., Amram, E. and Uzi, K. (eds). Marcel Dekker, Inc. (Publishers). New York, Basel. pp 205-220.

Reintam, E., Kuht, J., Loogus, H., Nugis, E., & Trukmann, K. (2005). Soil compaction and fertilisation effects on nutrient content and cellular fluid pH of spring barley (*Hordeum vulgare* L.). *Agronomy journal, 3*(2): 189 202.

Reszkowska, A., Krümmelbein, J., Peth, S., Horn, R., Zhao, Y., & Gan, L. (2011). Influence of grazing on hydraulic and mechanical properties of semiarid steppe soils under different vegetation type in Inner Mongolia, China. *Plant and Soil,* 340(1-2), 59-72.

Reznik, Y.M. (2007). Influence of physical properties on the deformation characteristics of collapsible soils. *Engineering Geology, 92*(1-2), 27-37.

Romero, E., Della, V. G., & Jommi, C. (2011). An insight into the wáter retention properties of compacted clayey soils. *Géotechnique, 61*(4), 313-330.

Rosegrant, M., Paisner, M. S., Meijer, S., & Witcover, J. (2001). *Global Food Outlook: Trends, Alternatives, and Choices*. International Food Policy Research Institute, Washington, D.C. pp 1-24.

Rusinamhodzie, L., Corbeels, M., Van, W. M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for sustainable development, 31*(4), 657-690.

Sadras, V. O. (2009). Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. *Irrigation Science. 31*(4), 183190.

Sakeus, K. (2016). *Anaerobic digestion of diary manure wastewater, food and fruit waste, a sustainable source of bio-energy and waste management.* Stellenbosch: Stellenbosch University.

Sangina N., & Woomer L. P. (2009). Integrated Soil Fertility Management in Africa: Principle, Practices and Developmental Process.

Sango, L., & Salvador, R. J. (1998). Influence of plant height and of leaf number on maize production at high plant densities. *Área de Informação da Sede Artigo em periódico indexado (ALICE).*

Savala, C. E. N., Omare M. N., & Woomer, P. L. (2003). Organic Resources Management in Kenya, Perspectives and Guidelines.

Schroth, G., Garcia, E., Griscom, B. W., Teixeira, W. G., & Barros, L. P. (2016). Commodity Production as restoration driver in the Brazilian Amazon Pasture-agro-forestation with cocoa (*Theobroma cacao*) in southern Para. *Sustainability Science, 11*(2) 277-293.

Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., & Manning, D. A. C. (2011). Persistence of soil organicmatter as an ecosystem property. *Nature*, *478*(7367), 49

Schwartz D. J. (2014). Soil as Carbon Storehouse: New Weapon in Climate Fight? Retrieved from http://www.e360.yale.edu>features>soil_as_c

Shah, N. A., & Tanveer, M. (2017). Environmental Science and Pollution Research 24. Retrieved from https://link.springer.com/article/10.1

Sheoran, V., Sheoran, A. S., & Poonia, P. (2010). Soil reclamation of abandoned mine land by revegetation: a review. *International Journal of Soil, Sediment and Water, 3*(2), 13.

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world. Past successes and future challenges to the role played by maize in global food security. *Food Security, 3*(3), 307-345.

Siczek, A., & Lipiec, J. (2011). Soybean nodulation and nitrogen fixation in response to soil compaction and surface straw mulching. *Soil and Tillage Research*, *114*(1), 50-56.

Simons, B. (2016). Simulation-based exploration of the thermal performance of selected multi-storey office building in Accra, Ghana.

Smith, S. E., Jacobsen, I., Gronlund, M., & Smith, F. A. (2011). Roles of arbuscular mycorrhizas in plant phosphorus (P) nutrition: interactions between pathways of P uptake in arbuscular mycorrhizal (AM) roots have important implications for understanding and manipulating plant P acquisition. *Plant Physiology*, 111, (174-581).

Soane, B. D., & Van Ouwerkerk, (1998). Soil compaction: A global threat to sustainable land use. *Advances in GeoEcology 31*: 517-525. Soil fertility and fertilizers ,3rd edition ,Tisdale and Nelson (1975) Macmillan publishing co,inc.new York. NY

Soane B. D., Ball, B. C., Arvidsson, J., Basch, G., Moreno, F., & Roger-Estrade, J. (2012). No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil and Tillage Research, 111*, (66-87).

Steffens, M., Kölbl, A., Totsche, K. U., & Kögel-Knabner, I. (2008). Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (PR China). *Geoderma*, *143*(1-2), 63-72.

Stepniewski, W., Alinski, J., & Ball, B.C. (1994). Effects of soil compaction on soil aeration properties. In: Saone, B. D. and Van Ouwerkerk. C. (Eds.). *Soil compaction in crop production*. Elsevier, Amsterdam. pp. 167-189.

Taylor, H. (1983). Managing root systems for efficient water use: overview. In: Taylor, H. M., Jordon, W. R. & Sinclaire, T. R. (Eds.), *Limitations to efficient water use in crop production*. ASA-CSSSA-SSSA, Madison, USA, pp 87-113.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Science, 108(50), 20260-20264.

Tracy, S. R., Black, C. R., Roberts, J. A., & Mooney, S. J. (2011). Soil compaction: a review of past and present techniques for investigating effects on root growth. Journal of the Science of Food and Agriculture, 91(9) Systems, 1528-1537.

Turmel, M., Speratti, A., Baudron, F., Verhulst, N., & Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. *Agricultural Systems, 134,* 6-16.

Usaborisut, P., & Niyamapa, T. (2010). Effects of machine-induced soil compaction on growth and yield of sugarcane. *American Journal of Agricultural and Biological Sciences 5* (3), 269-273.

USDA. (2016). US Department of Agriculture (USDHHS/USDA). (2015). 2015- 2020. Dietary Guidelines for Americans.

Verhulst, N., Govaerts, B., Verachetert, E., Castellanos-Navarerte, A., Mezzalama M., Wall, P., & Sayre, K. K. (2010). Conservation agriculture, improvingsoil quality for sustainable production systems. *Advances in soil science: Food security and soil quality.* CRC Press, Boca Raton, FL, USA, 137 208.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chronic acid titration method. *Soil Science, 37*(1), 29-38.

Wang, H., Jones, B., Li, Z., Frasse, P., Delalande, C., Regad, F., & Bouzayen, M. (2005). The tomato Aux/IAA transcriptions factor IAA9 is involved in fruit development of drought stress in plants. *Australian Journal of Crop Science, 5*(6), 764-789.

Williams, S. M., & Weil, R. R. (2004). Crop cover root channels may alleviate soil compaction effects on soybean crop. *Soil Sci. Soc. Am. J. 68*:1403-1409.

Wolkowski, R., & Lowery, B. (2008). Physical effects of soil drying on roots and crop growth. *Journal of Experimental Botany, 60*(10), 2845-2857.

World Bank. (1997). The Use of Compost In Indonesia: Proposed Compost Quality Standards.

Zhou. P (2017). Evaluating Soil Physical and Chemical Properties Following. Addition of Non-composted Spent Coffee and Tea for Athletic Fields.

Zhou, Gan, Z. T., Shangguan, Z. P., & Dong, Z. B. (2010). Effects of grazing on soil physical properties and soil erodibility in semiarid grassland of the Northern Loess Plateau (China). *Catena, 82*(2), 87-91.

APPENDICES

Appendix A

Site allocation design

Mild (BLK 1) **Moderate 2 (BLK 2)**

M C	M C	P C	P C	C C	P C
C C	P C	C C	M C	C C	M C
P C	C C	M C	C C	M C	P C
M C	C C	P C	M C	P C	C C
M C	P C	C C	C C	C C	P C
P C	C C	M C	M C	P C	P C
M C	P C	M C	C C	M C	P C
P C	C C	C C	M C	M C	C C

High (BLK 3) **NTP (BLK 4)**

Appendix B

WEIGHT OF THE COMPOST

Maize compost	1.2 kg per the area of a subplot (4m $\times$ 3m)
Cassava compost	1.2 kg per the area of a subplot (4m $\times$ 3m)
Pineapple compost	1.2 kg per the area of a subplot (4m $\times$ 3m)

Appendix C

DATA COLLECTION SHEET

NO / ZERO TRACTOR PASSES

S/N	Date/Week	Plot Number / Block	Seed Emergence	Germination Percentage	Plant Height	Stem Girth	No. of Leaves	Leaf Area	Ground Area	Cob formation	Treatment (compost type)
				%	m	Cm		m^2	m^2		
1	24/01/19	Block 4		95	0.07		2				Maize
2	24/01/19	Block 4		95	0.06		2				Maize
3	24/01/19	Block 4			0.09		3				Maize
4	24/01/19	Block 4			0.08		2				Cassava
5	24/01/19	Block 4			0.08		3				Cassava
6	24/01/19	Block 4			0.07		3				Cassava
7	24/01/19	Block 4			0.07		2				Pineapple
8	24/01/19	Block 4			0.07		2				Pineapple
9	24/01/19	Block 4			0.09		4				Pineapple
10	24/01/19	Block 4			0.08		3				Cassava
11	01/02/19	Block 4		95	0.11	2-8	5	h = 23cm w = 2cm	r = 11		Maize
12	01/02/19	Block 4		95	0.16	3.0	5	h = 25cm w = 2.5cm	r = 12		Maize
13	01/02/19	Block 4		95	0.19	3.4	6	h = 29cm w = 3cm	r = 11		Cassava

Appendix D

DATA COLLECTION SHEET

MILD TRACTOR PASSES

S/N	Date/Week	Plot Number / Block	Seed Emergence	Germination Percentage	Plant Height	Stem Girth	No. of Leaves	Leaf Area	Ground Area	Cob formation	Treatment (compost type)
				%	m	Cm		m^2	m^2		
1	24/01/19	Block 1		95	0.08		2				Maize
2	24/01/19	Block 1		95	0.09		3				Cassava
3	24/01/19	Block 1		95	0.07		3				Pineapple
4	24/01/19	Block 1		95	0.08		2				Cassava
5	24/01/19	Block 1		95	0.08		3				Pineapple
6	24/01/19	Block 1		95	0.07		2				Maize
7	24/01/19	Block 1		95	0.09		3				Maize
8	24/01/19	Block 1		95	0.08		3				Cassava
9	24/01/19	Block 1		95	0.08		2				Pineapple
10	24/01/19	Block 1		95	0.07		2				Pineapple
11	01/02/19	Block 1		95	0.11	2-8	5	h = 20cm w = 3cm	r = 9		Maize
12	01/02/19	Block 1		95	0.16	3.0	5	h = 16cm w = 2cm	r = 8		Maize

Appendix E

DATA COLLECTION SHEET

MODERATE TRACTOR PASSES

S/N	Date/Week	Plot Number / Block	Seed Emergence	Germination Percentage	Plant Height	Stem Girth	No. of Leaves	Leaf Area	Ground Area	Cob formation	Treatment (compost type)
				%	m	cm		m^2	m^2		
1	24/01/19	Block 2		80	0.06		3				Maize
2	24/01/19	Block 2		80	0.07		3				Maize
3	24/01/19	Block 2		80	0.09		2				Maize
4	24/01/19	Block 2		80	0.085		3				Cassava
5	24/01/19	Block 2		80	0.08		2				Cassava
6	24/01/19	Block 2		80	0.09		3				Cassava
7	24/01/19	Block 2		80	0.07		3				Pineapple
8	24/01/19	Block 2		80	0.07		2				Pineapple
9	24/01/19	Block 2		80	0.08		3				Pineapple
10	24/01/19	Block 2		80	0.08		2				Maize
11	01/02/19	Block 2		90	0.21	2.7	5	h = 22cm w = 2.7cm	r = 20		Maize
12	01/02/19	Block 2		90	0.17	2.8	5	h = 19cm w = 2.8cm	r = 16		Maize
13	01/02/19	Block 2		90	0.16	2.6	4	h = 20cm w = 2.8cm	r = 17		Maize

Appendix F

Chemical composition of compost used in the study

Parameter	Percentage
pH	8.93
Organic Carbon	14.00
Total Nitrogen	1.20
Total Phosphorus	0.90
Total Potassium	28.80
CEC	76.00

APPENDIX G

Calculation of Compost

Hectare

1 hectare of land = 10000 m^2

1 ton of compost = 1000 kg

Area of site = 42.5 m × 19 m = 807.5 m^2

Therefore if 10000 m^2 = 1000 kg

then, 807.5 $m^2 = x$

$$x = \frac{807.5\,m^2 \times 1\,000\,kg}{10000 m^2}$$

$$x = \frac{807500\,m^2 kg}{10000 m^2}$$

$x = 80.75\,kg$

From the calculation above we can say if 1 hectare requires 1 ton then, 807.5 m^2 also will require 80.75 kg

Further breakdown

Therefore 1 m^2 will require the following quantity of compost

807.5 m^2 = 80.75 kg

then 1m^2 = ?

$$= \frac{80.75\,kg \times 1\,m^2}{807.52\,m^2}$$

= 0.1 kg

therefore, 1m^2 requires 0.1 kg of compost

the area of plot is 4 × 3 = 12 m^2

from the above,

if 1 m^2 = 0.1 kg

then 12 m^2 = y

$y = \frac{12\ m^2 \times 0.1\ kg}{1\ m^2}$

$y = 1.2\ kg$

This implies that one plot ($4 \times 3 = 1.2$ kg)

One block (12 plots) $= 1.2\ kg \times 12 = 14.4\ kg$

two blocks (24 plots) $= 1.2\ kg \times 24 = 28.8\ kg$

three blocks (36 plots) $= 1.2\ kg \times 36 = 43.2\ kg$

four blocks (48 plots) $= 1.2\ kg \times 48 = 57.6\ kg$

maize compost in each block is 4.8 kg

cassava compost in each block is 4.8 kg

pineapple compost in each block is 4.8 kg

maize compost in the four blocks is 19.2 kg

cassava compost in all the four blocks is 19.2 kg

pineapple compost in all the four blocks is 19.2 kg

Appendix H

TEST MADE AT THE LAB FOR COMPOST

Compost sample	Carbon	% Nitrogen
Maize residue	63.8381	2.1616
	63.0251	2.2063
	62.7213	2.2626
Cassava residue	58.1141	0.3578
	58.2818	0.3160
	58.4415	0.3245
Pineapple residue	55.0144	1.0163
	55.9394	1.0124
	55.7937	1.0497