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IMPACT OF DIFFERENT LEVELS OF SOIL COMPACTION AND SOIL AMENDMENTS ON THE GROWTH AND YIELD OF MAIZE AND SOYBEAN

BY

SEIDU I. BAWA

BSc. AGRICULTURE (HONS)

MAY, 2014

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE

IN

SOIL SCIENCE

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DECLARATION

I declare that I have personally, under supervision, undertaken the study submitted herein. This Thesis does not incorporate, without acknowledgement, any material previously submitted for a degree in any University and does not contain any material previously published except where due references has been cited.

SEIDU I. BAWA …………………………… …………………………

Signature Date

Certified by:

PROF. C. QUANSAH …………………………… …………………………..

(SUPERVISOR) Signature Date

DR. CHARLES KWOSEH ………………………… …………………………..

(Head of Department) Signature Date

ABSTRACT

Two factorial pot experiments arranged in a Completely Randomised Design (CRD) with three replications were carried out to assess the impact of different levels of soil compaction and soil amendments on root growth and biomass yield of maize (*Zea mays* L.) and soybean (*Glycine max* L.). The treatments were soil compactions (bulk densities as proxy) of 1.3, 1.5 and 1.7 Mg m^{-3} and soil amendments of control (no soil amendments), poultry manure, NPK fertilizer and ½ rate each of PM and NPK fertilizer. The soybean and maize were grown in plastic buckets filled with the test soil (Ferric Acrisol). At the bulk density of 1.7 Mg m^{-3}, aeration porosity was reduced below the critical level of 10 % favourable for gaseous exchange. Soil compaction reduced plant height of maize and soybean. Increasing soil compaction resulted in the accumulation of most of the root biomass in the uncompacted soil above the compacted layer. Addition of soil amendments increased the relative root biomass of maize in the uncompacted soil while that in the compacted soil was reduced. In the case of soybean, although the relative root biomass in the uncompacted soil was relatively greater than that of maize, application of soil amendments tended to slightly decrease the relative root biomass over that of the Control. High soil compaction induced more root growth in the uncompacted soil and periphery of the soil core than the compacted zone. The applied soil amendments significantly increased the RPR of both crops in relation to the control. The shoot biomass of both crops decreased with increasing soil bulk density. All the applied soil amendments significantly increased the shoot biomass of maize and soybean over the Control. The magnitude response of the crops to the soil amendments was greater in soybean than in maize. Soil compaction and amendments significantly influenced root: shoot ratio of both crops.

At the bulk density 1.3 to 1.5 Mg m^{-3}, the root: shoot ratio decreased with increasing compaction. Beyond the bulk density of 1.5 to 1.7 Mg m^{-3}, the root: shoot ratio increased with increasing soil compaction. The soil amendments applied significantly influenced the root: shoot ratio of maize but not soybean. The soil amendments increased the biomass of both root and shoot but more so in the former than the later. The amendment x compaction interaction showed that the root: shoot ratio was influenced by the type of crop (cereal legume) and the confounding effects of factor interactions on the relative increases/reduction in shoot and root growth. The uptake of N, P and K by maize and soybean decreased with increasing bulk density in the order of 1.3> 1.5> 1.7 Mg m^{-3}. The adverse soil conditions created by increasing soil compaction accounted for the reduction in mineral uptake. Apart from the potassium, application of the soil amendments increased the nutrient uptake of the crops. Soil compaction accounted for 52 to 100 % of the variations in the magnitude of the measured parameters of maize and 62 to 98 % were for soybean while soil porosity accounted for 78 to 97 % of the variation in maize and 50 to 86 % to variations observed in soybean. The ideal bulk density for shoot biomass production of both crops should be within the range of 1.3 to < 1.5 Mg m^{-3}. At soil bulk density of 1.5 Mg m^{-3} and above, soil amendment should be added to ameliorate the negative impact of soil compaction.

DEDICATION

This work is dedicated to my supervisor Prof. Charles Quansah, Mr. Awudu Abubakari, my wife Tang Gladys and to my children Hawa, Seidu Rutifia.

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CHAPTER ONE

1.0 INTRODUCTION

The urgent need to feed the ever growing population of Ghana (and elsewhere) has led to farmers are being encouraged to produce more food in order to meet the demand of the populace through the provision of incentives. The government of Ghana has therefore provided tractors, fertilisers and improved seeds to farmers. This is to shift the paradigm of using simple farming tools such as the hoe and cutlass to increased use of tractor mounted implements to enhance efficiency in farm operations. This invariably shortens the time needed to cultivate the soil and subsequently solves the problem associated with inadequate farm labourers.

Although tractor mounted implements ensure efficiency on farms, inappropriate use may cause physical degradation of the land with soil compaction being one of the major problems. Soil compaction caused by heavy machinery with high inflation pressure of the tires on wet soils happens mostly during soil tillage (Reintam *et al.*, 2005). It results in reduced soil porosity, high soil bulk density and root penetration resistance (Czyz *et al*., 2001; Lipiec and Hatano, 2003; Usaborisut and Niyamapa, 2010). These impede germination, seedling emergence, root and shoot growth and crop yield as a result of reduced soil fertility, aeration, hydraulic properties and, water and nutrient uptake (Ishag *et al*., 2001; Passioura, 2002; Lampurlanes and CanteroMartinez, 2003; Glab, 2007). It must, however, be emphasised that soil compaction in agricultural fields are not only attributed to tractor mounted implements. Grazing animals and anthropogenic activities are also contributing factors. Texture, moisture, structure and initial bulk density are soil factors which affect plants' response to compaction (Domzal *et al.*, 1991).

Currently, considerable attention is being paid to soil physical properties which may possibly inhibit the growth and development of roots and seedlings of crops in the field. This is due to the fact that problems associated with soil compaction are becoming more severe as the use of bigger and heavier farm machinery is promoted. According to Oldeman *et al*. (1991), about 18 million hectares of lands in Africa has been degraded by compaction resulting in sealing and crusting of soil.

Increasing the productivity of these lands will require the amelioration of soil compaction for prolific crop growth and yield. The study of root tolerance to soil compaction particularly under different soil amendments in the field where environmental conditions cannot be controlled is difficult, expensive and time consuming. Therefore, studies have been carried out in fairly controlled environments to facilitate the choice of interventions to adopt in order to deal with the problem of soil compaction.

In the field, this approach is time consuming and very expensive. Controlled experiments in the laboratory, however, offer a good opportunity in the screening of crop genotypes for tolerance to soil compaction (Asady *et al*., 1985).

1.1 Problem statement and justification

While much is known about the negative effects of soil compaction on the growth and yield of many crops, the impact of combined soil amendments and compaction caused by conventional tillage has not been extensively researched (Williams and Weil, 2004). Furthermore, the use of soil amendments to reduce the adverse impact of soil compaction on root growth has received less research attention. It is in the light of these research gaps that this study was carried out to contribute to the much needed information and knowledge on the impact of soil amendments in enhancing root growth and tolerance to soil compaction for sustained crop growth and yield.

1.2 Research objectives

1.2.1 Main objective

The main objective of the study was to assess the impact of different levels of soil compaction and soil amendments on root growth and biomass yield of maize and soybean.

1.2.2 Specific objectives

The specific objectives were to assess:

i. the impact of soil compaction on some soil physical properties ii. the growth and biomass yield of maize and soybean as affected by soil compaction and amendments iii. root growth and distribution as affected by soil compaction and amendments and iv. the impact of soil compaction and amendments on root: shoot ratio, root penetration ratio and nutrient uptake of maize and soybean.

1.3 Hypotheses

The above objectives were based on the following hypotheses.

i. Soil compaction reduces root and shoot growth of maize and soybean ii. Application of soil amendments ameliorate the impact of soil compaction on root and shoot growth

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Maize and soybean

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

Soybean (*Glycine max* (L.) Merrill) contains about 40 % protein and 20 % edible oil (Adu - Dapaah *et al*., 2004; MoFA and CSIR, 2005). It is the most widely used edible oil and is low in cholesterol, it has imperceptible odour and these make it the ultimate choice of vegetable oil for domestic and industrial food processing (Mpepereki *et al*., 2000).

The two crops were selected based on the fact that maize is the largest staple crop and soybean is an emerging major crop in Ghana. Additionally, dicotyledons (soybean) and monocotyledons (maize) responds differently to the impact of soil compaction and there is the need to investigate this phenomenon in Ghanaian soils.

2.2 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 and Lowery, 2008). It is a serious and an unnecessary soil degradation process that limits crop growth. Soils sensitivity to compaction depends on soil properties, mostly on texture and structure (Hakansson and Lipiec, 2000). However, the most important factor in making decisions about cultural operations is soil water due to its influence on soil compaction (Défossez *et al*., 2003).

Soil compaction is caused by natural as well as human and animal induced processes. Treading of wet soils by animals causes soil compaction (Drewry *et al.*, 2000).

Human activities such as the 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. The most yield limiting soil compaction is caused by wheels from heavy equipment, particularly on wet soils (Wolkowski and Lowery, 2008). A tillage induced compaction layer is mostly referred to as ―hardpan,‖ or ―plough pan‖ and occurs just below the plough depth (McKenzie, 2010). According to Drewry *et al. (*2000), Wolkowski and Lowery (2008) and McKenzie (2010), the process of tillage induced soil compaction are as follows (i) when soils are cultivated repeatedly 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) As soil particles are compressed, the pore space is reduced, thereby reducing the space available in the soil for air and water (iii) If the applied force is great enough, soil aggregates are destroyed (iv) The result is a dense soil with few large pores that has poor internal drainage and limited aeration.

Soil compaction was ameliorated through biological drilling in which root channels left by previous crops may reduce the effects of subsoil compaction on subsequent 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 subsurface soil water. No 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).

Subsoiling 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 and 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. However, the selection of crop cultivars having some tolerance to certain compacted soils is expensive using conventional plant breeding programs (Ghaderi *et al*., 1984).

The strategies outlined above for controlling compaction have led to increased crop yield although uncertainties regarding their use still remain. Soil amendments have been added to soils to decrease the effect of soil compaction on crop growth (Bowden, 2006). Addition of soil amendments increases the competitive advantage of the crop for nutrient uptake. This provides crops (roots) with the needed nutrients necessary for their growth and development, and reduces the limitations posed to root growth by compaction.

2.2.1 Impact of soil compaction on bulk density, aeration and porosity

Soil bulk density is inversely proportional to total porosity (Carter and Ball, 1993), which comprises the pore space available in the soil for air and water movement. 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 arrangement 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.

Soil aeration is one of the physical factors that limit the development of root systems and, growth and yield of crops on compacted soils (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 relate it to crop yield response due to soil compaction. Rab (2004) reported that macropore volume less than 10 % generally restricted root growth.

2.2.2 Impact of soil compaction on crop growth and Yield

A degraded soil due to compaction hinders root and shoot growth which results in low crop yield. Gediga (1991) and, Lowery and Schuler (1991) assessed the impact of subsoil compaction on the growth of maize and found significant reduction in the height and dry matter production of the crop as soil compaction increased. Atwell (1990) and, Lowery and Schuler (1991) similarly observed that the height and mass of shoots of crops were reduced in compacted soils when compared to those grown in non-compacted soils. Beutler and Centurion (2004) observed that soybean yield declined beyond a bulk density of 1.36 Mg m^{-3} on soils without fertilizer amendment and 1.48 Mg m^{-3} on soils that have been fertilized. Oussible *et al.* (1992) observed that the grain and straw yield of wheat decreased by 12-23 % and 4-20 % respectively when a clay loam soil was compacted to a bulk density of 1.52 Mg m^{-3} from an initial density of

1.33 Mg m^{-3}. Ishag *et al.* (2001) reported 38 and 39 % reduction in grain and straw yields of wheat respectively when the soil was compacted to a bulk density of 1.93 Mg m^{-3} from an initial bulk density of 1.65 M gm^{-3}. Ishag *et al.* (2001) posited that crop yields is reduced by soil compaction due to increased resistance to root growth and decrease in water and nutrient use efficiencies.

2.2.3 Impact of soil compaction on root growth and development

Soil compaction, especially in the subsoil layers may restrict deep root growth and plant access to subsoil water in the mid to late growing season when rainfall is usually sparse and evapotranspiration is high (McKenzie, 2010; Chen and Weil, 2011). Muhammad *et al.* (2012) reported that the adverse effect of soil compaction on water flow and storage may be more serious than its direct effect on root growth.

Root response to soil compaction depends on the presence and distribution patterns of pores having a diameter greater than the roots and on pore continuity. A soil matrix with larger pores are essential for optimal crop yields (Lampurlanes and CanteroMartinez, 2003). Soil compaction restricts root growth resulting in poor anchorage and susceptibility of plants to uprooting during grazing (Crush and Thom, 2011).

2.2.4 Impact of soil compaction on root penetration

High soil strength reduces and even stop root growth (Atwell, 1993). Soil strength is a measure of the ability of soils to resist deformation from an applied force (Wolkowski and Lowery, 2008). It increases as soil particles become more tightly pressed together. As soil strength increases, the plant roots must exert greater force to penetrate the soil. The most important factors which affect penetration resistance are soil water content and bulk density (Unger and Jones, 1998). Soil texture, organic matter (carbon), particle surface roughness and structure could also influence the penetration resistance of a soil (Cassel, 1982; Campbell and O'Sullivan, 1991).

Mechanical impedance to root growth is one of the most important factors determining root elongation and proliferation within a soil profile. It is experienced to varying degrees by virtually all roots growing through the soil and it restricts the rate of oxygen supply to roots (Bengough and Mullins, 1990). Roots follow tortuous paths seeking out the path of least soil resistance. They are generally unable to penetrate pores narrower than their own diameter (Campbell and Henshall, 1991; Lampurlanes and Cantero-Martinez, 2003). Roots extract water from the soil, excrrete mucilage from around their tips, and swell when physically impeded (Bengough and Mullins, 1990). As roots extend deep into the soil, they encounter restrictive layers, which cause root spread horizontally/laterally and are unable to fully utilize moisture and nutrients below this layer, and thus, limits plant growth (Wolkowski and 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 and 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 and Lal, 2005).

Tap-rooted species may penetrate compacted soils better than fibrous-rooted species and therefore be better adapted for use in ―biological tillage (Chen and 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 increase in root diameter in mechanically impeded roots results mainly from an increased thickness of the cortex; this is a consequence of both the increase in the diameter of the outer cells, and an increase in the number of cells per unit length of the root (Bengough and Mullins, 1990).

Malerechera *et al*. (1991) observed that monocot and dicot species respond differently to changes in soil. Dicot species are better at penetrating compacted soil layers than monocots (Materechera *et al*., 1993). However, some studies also suggest that dicots do not always generate greater maximum root growth than monocots (Clark and Barraclough, 1999).

Penetration resistance measured with the penetrometer is usually 2-8 times greater than that actually experienced by the root tip (Bengough and Mullins, 1990; Atwell, 1993) owing to the different ways by which roots and probes penetrate the soil. In well-structured soils or those in which bio-channels are preserved as in non-tilled soils, roots continue to extend at greater penetration readings because they can grow in the inter-aggregated spaces (Taylor, 1983; Cresswell and Kirkegaard, 1995). In contrast, penetrometers are rigid metal probes constrained to a linear path through the soil (Bengough and Mullins, 1990). They remain one of the most convenient method for predicting root resistance although careful interpretation of results and choice of penetrometer design are essential if accurate estimates of soil resistance to root elongation are to be obtained (Bengough and Mullins, 1990). Penetrometer values greater than 2 MPa are generally reported to produce a significant root growth reduction (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 root that penetrates the same core (Asady *et al.*, 1985). Ocloo (2011) observed that soil compaction reduced the root penetration ratio of maize and soybean seedlings.

2.2.5 Impact of soil compaction on root shoot: ratio

The root-shoot ratio is a representative indicator of environmental stress that is encountered by plants (Chiu *et al.*, 2006). Plants respond to their environment in a way to enhance their resource use (Agren and Franklin, 2003). Plants growing under extreme nutrient stress may also optimize their behaviour with respect to other variables in addition to relative growth rate (Agren and Franklin, 2003). One expression of such optimization is the allocation between roots and shoots in response to nutrient availability (Agren and Franklin, 2003). Understanding how the competition varies among crop species is essential for selecting varieties which can better withstand stress in a particular environment. Also, knowledge of nutrient allocation between roots and shoots can help agronomists choose the right agronomic practice in order to manage crops under stress.

Some researchers have made the biological assumption that root competition does not affect shoot competition (and vice versa) (Cahill, 2002). However, there is evidence that this assumption is not always valid (Cahill, 1999; Cahill, 2002). Grzesiak (2009) reported that soil compaction decreased dry matter of shoots and roots, while increasing the shoot-root ratio of maize. That is, the root-shoot ratio of maize decreased as soil compaction increased. Ocloo (2011) observed that the root-shoot ratio of maize increased as soil compaction increased. Dawkins *et al.* (1983) found out that the shoot: root ratio in peas was smaller when roots were growing in compacted soils than in loosened soils, suggesting that shoot growth might be more susceptible to compaction than root growth in peas. Sunflower plants grown in compacted soil had significantly lower root-shoot ratios than those grown in noncompacted soil (Goodman and Ennos, 1999). Atwell (1990) found that the root-shoot ratio in winter wheat was smaller when roots were growing in compacted soils than in normal soils because soil compaction consistently inhibited the elongation of seminal root axes.

Root and shoot competitions are not independent, but instead interact to affect plant growth (Cahill, 2002). This strongly suggests that simply measuring the strength of one component of competition (either root or shoot) along a productivity gradient reveals very little about the overall importance of that competitive form on plant growth (Cahill, 2002). The form of interaction between root and shoot competition varied both as a function of species identity and fertilization (Cahill, 2002; Reich, 2002). Grzesiak (2009) observed that the impact of soil compaction on shoot-root ratio were greater for maize than for triticale (*Triticale hexaploide* Lart.).

Cahill (2002) posited that (i) changes in allocation patterns that increase the ability of plants to compete above ground may come at the cost of below ground competitive ability (or vice versa); and (ii) that, since the ability to make morphological shifts in response to changes in the environment is species specific, it is also likely that interactions between root and shoot competition vary among species. This suggests that the intensity of competition experienced by individual plants is not a characteristic of the community but instead an interaction between the neighbourhood surrounding, an individual plant and that plant‘s ability to respond.

Plants respond to nutrients by changing their root: shoot ratios. The most visible response of nitrogen availability is an increased shoot growth and that of phosphorus is an increased in root growth (Agren and Franklin, 2003). Although, other studies suggests that both nitrogen and phosphorus stimulate both root and shoot growth. When nitrogen is optimum but phosphorus is deficient, phosphorus addition promotes shoot as well as root growth (Ericsson, 1995). Similarly, when phosphorus is optimum and nitrogen is deficient, additions of nitrogen stimulate both root and shoot growth (Cahill, 2002). One hypothesis used to explain these allocations is that plants optimize their behaviour by maximizing their relative growth rate (Agren and Franklin, 2003). Cahill (2002) observed that fertilization caused a shift in the rootshoot interaction, but not in the total strength of root and shoot competition and suggested that the root-shoot interaction is a highly labile variable (Cahill, 2002). If root-shoot interactions are common in natural systems, then simply measuring the strength of one form of competition in no way provides any information about the overall importance of that competitive form to plant growth (Cahill, 2002).

In general, when nutrient availability increases, plants allocate relatively less to their roots, which is consistent with a resource optimization hypothesis which states that increased nutrient availability indicates that less effort is required to acquire this resource (Agren and Franklin, 2003). Also, there is proportionally greater root than shoot systems when nutrient are in short supply (Reich, 2002). Although the above ideas have been taken as near-paradigm by several physiologists and ecologists, there is a need for supportive evidence for these ideas (Reich, 2002).

2.3 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 both chemical and organic fertilizers have increased the growth and yield of crops. Onwonga *et al*. (2013) reported that application of soil amendments increased soil available P, its uptake and maize yields over the control. Rostami *et al.* (2012) reported that maximum soybean biomass (14859.4 kg ha^{-1}) and grain yield (4426.9 kg ha^{-1}) were obtained when enriched municipal solid waste (MSW) compost was applied. Pirdashti *et al.* (2010) showed that once application of MSW (20 and 40 Mg ha^{-1}) compost and chemical fertilizer significantly increased soybean yield (about 34 %) as compared to non-amended soil. Application of NPK fertilizer increased the yield of maize (Raza *et al*., 2005; Law-Ogbomo and Law-Ogbomo, 2009; Obidiebube *et al.*, 2012) and soybean (Rostami *et al*., 2012).

Investigations have shown that application of organic amendments recorded higher soybean biomass and yield in comparison to chemical fertilizers. Rostami *et al.* (2012) observed that using municipal solid waste compost produced higher biomass and grain yield of soybean compared to chemical fertilizer treatment, although, application of both the chemical and organic amendments increased soybean biomass in relation to the control.

Organic amendments are rich in a wide range of plant nutrients and the presence of non-nutritive constituents or benefits within the organic amendments may lead to better crop growth (Bowden, 2006). Combinations of both organic and mineral N sources have increasingly received recognition as integral and indispensable components of sustainable soil fertility management (Mugendi *et al.*, 2007). Soils to which sole organic amendments or their combinations with mineral fertilizer were applied produced higher grain yield of maize than where the recommended mineral fertilizer was applied alone (Mugendi *et al.*, 2007). The combination of organic and mineral soil amendments may assist in synchronization of nutrient release and uptake by the crop grown (Kimetu *et al.*, 2004). Sole organic amendments or their integration with mineral fertilizers can serve as substitute to the use of mineral fertilizers (its use is limited) among small scale farmers (Kimetu *et al.*, 2004).

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.

2.4 Impact of soil amendments and compaction on crop nutrient uptake The ability of plants to obtain water and nutrients from the soil is related to their ability to develop extensive root systems (Chen and 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). It can lead to increased loss of nitrogen by denitrification, which is the conversion of plant available nitrate into gaseous nitrogen forms that are lost to the atmosphere (McKenzie, 2010). 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. Soil amendments restores soil quality by balancing pH, adding organic matter, increasing water holding capacity, reestablishing 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 organic manure 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.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The pot experiment was setup at the Department of Horticulture of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. The soil for the experiment was sampled from the Plantation Section, KNUST and belongs to the Asuansi series (Adu, 1992), classified according to FAO (1990) as Orthi-Ferric Acrisol. The soil sample was taken from a depth of 0 – 40 cm.

3.2 Experimental Design

Two experiments were conducted using maize (*Zea mays* L.) and soybean (*Glycine max* L.) as test crops. Each experiment was a 3×4 factorial arranged in a Completely Randomised Design (CRD) with three replications. The treatments were soil at three compaction levels or bulk densities: 1.3, 1.5 and 1.7 Mg m^{-3}; and four levels of soil amendments: control (no soil amendments), poultry manure, NPK fertilizer and ½ rate each of poultry manure and NPK fertilizer combined.

3.3 Test crops

The maize and soybean varieties used were Obatampa (an open pollinated variety) and Anidaso respectively.

Plate 1: Experimental layout of the maize crop under the different treatments

Plate 2: Experimental layout of the soybean crop under the different treatments

3.4 Soil amendments and application

The NPK was surface-applied at the rate of 60:60:60 kg N, P_20_5 and K_20 per hectare. For an area of 0.07 m^2 of the 12 L bucket used for the experiment, this was equivalent to 0.42 g. To supply this amount from NPK 15:15:15 fertilizer required an application of 2.87 g per bucket. The mineral fertilizer N equivalent of 0.42 g was used as the basis for the amount of poultry manure to apply. With an N content of 2.79 % in the poultry manure, this gave 15 g. The 15 g of poultry manure (2.79 % N, 0.95 % P and 3.46 % K) supplied 0.42 g N, 0.32 g P_20_5 and 0.62 g K_20. Thus the following quantities of soil amendments were applied:

i. Control- no amendments ii. 100 % NPK= 2.89 g 15:15:15 NPK fertilizer iii. 100 % NPK= 15 g Poultry manure iv. ½ Rate NPK + ½ Rate Poultry manure = 1.45 g 15:15:15 NPK+7.5 g

Poultry manure

3.5 Physico-chemical analysis of the poultry manure

3.5.1 Total nitrogen in poultry manure

Total N was determined using the Kjeldahl digestion method. Two (2.0) grams of poultry manure oven-dried and ground to pass through a 0.5 mm sieve was weighed into a 500 ml Kjeldahl digestion flask and one spatula of catalyst (copper sulphate + sodium sulphate + selenium powder mixture) followed by 20 mL of concentrated H_2SO_4 was added. The mixture was heated to digest the poultry manure to a permanent clear green colour. The digest was cooled and transferred to a 100 mL volumetric flask and the volume was made up to the mark with distilled water. A 10 mL aliquot of the digest was transferred into a Tecator distillation flask and 20 ml of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask.

The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 N HCl solution. A blank digestion, distillation and titration were carried out as a check against traces of nitrogen in the reagents and water used (Okelabo et al., 1993).

Calculation:

$$\%N = \frac{(a - b) \times 1.4 \times N \times V}{s \times t}$$

Where a = volume of HCl used for sample

titration b = volume of HCl used for blank

titration 1.4 = 14 x 10^{-3} x 100 % (14 = atomic

weight of N)

N= normality of HCl.

V = total volume of digest

S = mass of oven dry plant sample taken for digestion in grams (2.0 g) t

= volume of aliquot taken for distillation (10.0 ml)

3.5.2 Phosphorus determination in the poultry manure

A 5 ml aliquot of the supernatant digest was pipetted into a 50 ml volumetric flask. Five (5.0) millilitres of ammonium molybdate – ammonium vanadate solution was added. Volume of mixture was made up with distilled water to the 50 ml mark and allowed to stand undisturbed for 30 minutes for colour development. Standard curve was developed concurrently with P concentrations ranging from 0.0, 5.0, 10.0, 15.0,

20.0 mg P / kg. The absorbance of blank, control and the samples were read on the Jenway Colorimeter at a wavelength of 430 nm.

A graph of absorbance verses concentration (ppm) P was plotted. The blank and unknown standards were read and the ppm P was obtained by interpolation on the graph plotted from which P concentrations were determined.

Calculation:

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

Pm content (g) in 100 g plant sample, (% P) $= \frac{c*df*100}{1000000}$

$$= \frac{c*1000*100}{1000000}$$

$$= \frac{c}{10}$$

Where,

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

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

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

3.5.3 Determination of potassium in poultry manure

The potassium in the supernatant digest was determined using Jenway PFP 7 Flame photometer. Standard solutions of KH_2PO_4 with concentrations of 0, 200, 400, 600, 800 and 1000 mg/L were prepared and emissions read from the photometer. The K emissions of the poultry manure samples were also read from the photometer. A graph of emissions verses concentrations of the standards were plotted from which the K concentrations of the poultry manure samples were calculated.

Calculation:

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

K content (g) in 100 g plant sample, (% K) = $\frac{c*df*100}{1000000}$

$= \frac{c*100*100}{1000000}$

$= \frac{c}{100}$

Where,

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

= dilution factor, which is 100 x1 = 100, calculated as :

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

3.6 Physico-chemical analysis of the soil

3.6.1 Soil pH

Soil pH was determined in 1:1 suspensions of soil and water using a standard pH meter. Ten gram of soil sample was weighed into 100 mL polythene bottles. To this, 10 mL of distilled water was added and the bottle stirred and allowed to stand for 30 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the glass electrode into the upper part of the suspension.

3.6.2 Soil organic carbon (SOC)

Organic carbon was determined by Walkley and Black wet combustion method (Nelson and Sommers, 1982). Two grams of soil sample was weighed into a 400 mL flask and, 10 mL and 20 mL of 1.0 N potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 were added respectively. This was swirled to ensure contact with all the soil particles. The flask was made to stand on an asbestos sheet for 30 minutes to cool. A 200 mL distilled water was added after which 10 mL of 85 % orthophosphoric acid (H_3PO_4) and 2 mL of barium diphenyl sulphate indicator were added. The solution was titrated with 1.0 N ferrous sulphate for a colour change from blue to bright green end point. A blank titration was carried out without soil. Percent carbon was calculated as:

$$\% \text{ Organic C} = \frac{1.0 \text{ N FeSO4} \times (\text{V1} - \text{V2}) \times 0.39}{W}$$

Where:

1.0 N $FeSO_4$ is Normality of $FeSO_4$ used for titration

V1 = mL for blank titration

V2 = mL for sample titration

W= weight of soil sample used

0.39= 3 × 0.001 × 100% × 1.33 (3 = equivalent weight of C)

1.3 = a composition factor for the incomplete combustion of the organic matter.

3.6.3 Total Nitrogen

Total nitrogen was determined by the modified Kjeldahl digestion method (Bremner and Mulvaney, 1982). In this method, 10 g of soil was digested with 30 mL concentrated sulphuric acid, using a catalyst tablet of sodium sulphate (100), copper sulphate (10) and selenium (1). Digestion was followed by the Kjeldahl distillation process, using 40

% caustic soda solution (NaOH) to distil ammonia which was received into 4 % boric acid. Titration was done using 0.1 N HCl.

Calculation:

$$\% \text{ Total N} = \frac{\text{N} \times (\text{a} - \text{b}) \times 1.4 \text{ mcf}}{\text{S}}$$

Where:

N = Normality of the HCl used in the titration a = mL

HCl used in sample titration b = mL HCl used in blank

titration S = weight of air- dried sample (g) mcf =

moisture correction factor (100 + % moisture)/ 100

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of nitrogen)

3.6.4 Exchangeable Cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate (NH_4OAc) solution at pH 7 and exchangeable acidity (hydrogen and aluminum) was determined in 1.0 M KCl extract (Okalebo *et al.*, 1993).

3.6.5 Extraction of exchangeable bases

Ten grams of soil was weighed into an extraction bottle and 100 mL of 1.0 *M* ammonium acetate solution was added. This was shaken for one hour. At the end of the shaking, the supernatant solution was filtered using a No. 42 Whatman filter paper.

3.6.6 Determination of calcium and magnesium

A 10 mL portion of the extract was transferred to an erlenmeyer flask and 5 mL of ammonium chloride-ammonium hydroxide buffer solution was added followed by 1 mL of triethanolamine. Few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was titrated with 0.02*N* EDTA solution from red to blue end point.

Calculations:

$$Ca^{2+} + Mg^{2+} \text{ (or Ca) (cmol/kg soil)} = \frac{0.02 \times V \times 1000}{W}$$

Where:

W = weight in grams of soil extracted

V = ml of 0.02 *M* EDTA used in the titration

0.02 = concentration of EDTA used

3.6.7 Determination of Calcium only.

A 20 mL portion of the extract was transferred to a 25 mL Erlenmeyer flask and the volume made up to about 50 mL with distilled water. Hydroxylamine hydrochloride (1.0 mL), potassium cyanide (1.0 mL of 2 % solution) and potassium ferrocyanide (1.0 mL of 2 %) were added. After a few minutes 4 mL of 8.0 M potassium hydrochloride and a spatula of mureoxide indicator were added. The solution obtained was titrated with 0.002 M EDTA solution to a pure blue colour. Twenty milliliters of 0.01 M calcium chloride solution was titrated with 0.02 M EDTA in the presence of 25 mL 1.0 M ammonium acetate solution to provide a standard pure blue colour.

Calculations;

$$\text{Ca + Mg (or Ca) (cmol/ kg soil)} = \frac{0.02 \times (Va - Vb) \times 1000}{0.1 \text{ x } W}$$

Where:

W = weight in grams of air-dried soil extracted

Va = mL of 0.002 M EDTA used in the titration Vb

= mL of 0.002 M EDTA used in blank titration

0.002 = concentration of EDTA used.

3.6.8 Exchangeable potassium and sodium determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting 1000 mg/L of potassium and sodium solutions to 100 mg/L. This was done by taking 25 mL portion of each into a 250 mL volumetric flask and water added to make up for the volume. Portions of 0, 5, 10, 15 and 20 mL of the 100 mg/L standard solution were put into 200 mL volumetric flasks respectively. One hundred milliliters of 1.0 M HH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/L for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculation:

$$\text{Exchangeable K (cmol/ kg soil)} = \frac{(a-b)\ x\ 250\ x\ mcf}{10\ x\ 39.1\ x\ S}$$

$$\text{Exchangeable Na (cmol/ kg soil)} = \frac{(a-b)\ x\ 250\ x\ mcf}{10\ x\ 23\ x\ S}$$

Where:

a = mg/L of K or Na in the diluted sample percolate b

= mg/L of K or Na in the diluted blank percolate

S = air-dried sample weight of the soil in gram

Mcf = moisture correction factor
39.1 = Molar mass for potassium

23 = Molar mass for sodium

3.6.9 Exchangeable acidity

Exchangeable acidity is defined as the sum of Al^{3+} and H^{+}. The soil sample was extracted with unbuffered 1.0 M KCl and the sum of Al and H determined by titration.

Fifty grams of soil sample was put in a 200 mL plastic bottle and 100 mL of M KCl solution added. The bottle was capped and shaken for 2.0 hours and then filtered. Fifty milliliters portion of the filtrate was taken with a pipette into a 250 mL Erlenmeyer flask and 2-3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 M NaOH until the colour just turned permanently pink.

A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmol/ kg soil)} = \frac{(a - b) \times M \times 2 \times 100 \times mcf}{S}$$

Where:

a = mL NaOH used to titrate with sample

b = mL NaOH used to titrate with blank M

= molarity of NaOH solution

S = air-dried soil sample weight in gram 2 = 100/50 (titre / pipette

volume) mcf = 3223222moisture correcting factor (100 + %

moisture) / 100

3.7.1 Effective cation exchange capacity (ECEC) determination

Effective cation exchange capacity was determined by the sum of exchangeable bases (Ca^{2+}, Mg^{2+} K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+}).

3.7.1.1 % Base saturation determination

Per cent base saturation was determined by dividing the total exchangeable bases (TEB) by effective cation exchange capacity (ECEC). This was multiplied by 100.

Calculation:

$$\text{\% Base saturation} = \frac{TEB\ x\ 100}{\text{ECEC}}$$

3.7.1.2 Available phosphorus (P)

The available phosphorus was determined using the Bray P_1 method as described by Olsen and Sommers (1982). The method is based on the production of a blue complex of molybdate and orthophosphate in an acid solution. A standard series of 0, 0.8, 1.6, 2.4, 3.2, and 4.0 µgP/mL were prepared by diluting appropriate volumes of 10 µgP/mL standard sub-stock solution. These were subjected to colour development and their respective transmittances read on a spectrophotometer at a wavelength of 520 nm. A standard line graph was constructed using the readings.

A 2.0 g of soil sample was then weighed into a 50 mL shaking bottle and 20 ml of Bray-1 extracting solution was added. The sample was shaken for one minute and then filtered through No. 42 Whatman filter paper. Ten millilitres of the filtrate was pipetted into a 25 mL volumetric flask and 1 ml each of molybdate reagent and reducing agent were added for colour development. The percent transmission was measured at 520 nm wavelength on a spectrophotometer. The concentration of P in the extract was obtained by comparing the results with a standard curve.

Calculations:

$$P\ (mg\ kg^{-1}) = \frac{\text{Graph reading} \times 20 \times 25}{w \times 10}$$

where:

w = sample weight in grams
20 = mL extracting solution

25 = mL final sample solution

10 = mL initial sample solution

3.7.1.3 Particle size distribution (Clay, Silt and Sand)

The hydrometer method as described by Bouyoucos (1963) was used for this analysis.

A 51 g soil sample was weighed into a ‗milkshake' mix cup. To this, 50.0 ml of 10 % sodium hexametaphosphate along with 100 ml distilled water were added. The mixture was shaken for 15 minutes after which the suspension was transferred from the cup into a 1000 ml measuring cylinder and distilled water was added to reach the 1000 ml mark. The mixture was inverted several times until all soil particles were in suspension. The cylinder was placed on a flat surface and the time noted. The first hydrometer and temperature readings were taken at 40 seconds. After the first readings the suspension was allowed to stand for 3 hours and the second hydrometer and temperature readings taken. The first reading indicates the percentage of sand and the second reading percentage clay.

Calculations:

% Sand = 100 – [H_1 + 0.2 (T_1 – 20) – 2.0] x 2

% Clay = [H_2 + 0.2 (T_2 – 20) – 2.0] x 2

% Silt = 100 – (% sand + clay)

Where:

H_1 = Hydrometer reading at 40 seconds

T_1 = Temperature at 40 seconds (^{0}C)

H_2 = Hydrometer reading at 3 hours

T_2 = Temperature at 3 hours (^{0}C)

0.2 (T – 20) = Temperature correction to be added to hydrometer reading
- 2.0 = Salt correction factor to be added to hydrometer reading.

3.7 .1.4 Soil compaction using bulk density as proxy.

Three levels of bulk density 1.3, 1.5, 1.7 Mg m^{-3} were studied. Bulk density was computed as:

$$\ell b = \frac{Ms}{Vt}$$

ℓb=bulk density

Where: Ms= mass of air dried soil (Mg)

Vt =Total volume of soil (m^3)

Bulk density was standardized in the buckets used for the experiment.

3.7.1.5 Moisture content

Soil water content was determined on volume basis. Moist soil samples were taken from the buckets two days after drainage following saturation when the soil was assumed to be at or near field capacity, defined as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially ceased which is attained after 48–72 hours of drainage (Veihmeyer and Hendrickson, 1931; USDA-NRCS, 2008). Soil samples were collected with the core sampler and sent to the laboratory where they were weighed to find their initial masses. They were then oven-dried at a temperature of 105^oC to a constant mass M_s. The loss of water upon drying constituted the mass of water M_w contained in the sample. Moisture content was determined on volume basis from the relation:

$$\theta_v = \theta_g \times \left(\frac{\rho_b}{\rho_w}\right)$$

Where, θ_g is the gravimetric water content, ρ_b is the dry bulk density and ρ_w is the density of water (assumed to be 1.0 Mg m^{-3}).

$$\theta_g = \left(\frac{M_w}{M_s}\right)$$

Where, M_t is total mass of moist soil is M_s is the mass of the solid components of the soil and M_w is the mass of water contained in the soil.

$$M_w = M_t - M_s$$

3.7.1.6 Total Porosity

Total porosity of the soil core in the bucket was determined as

$$\% \text{ f} = (1 - (\frac{\ell b}{\ell s})) \times 100$$

Where: % f= total porosity

ℓb = bulk density (Mg m^{-3})

ℓs = particle density (2.65 Mg m^{-3})

3.7.1.7 Preparation of the plastic buckets for the experiment

Seventy- two 12 L volume plastic bucket were used for the experiment, 36 bucket each for maize and soybean. Each bucket was graduated at 2 L interval and had a surface area of 0.07 m^2. Each bucket assembly consisted of a top 2 L space for watering, followed by a 2 L soil core (1.3 Mg m^{-3}), and a bottom 8 L core for the 3 levels of compaction (1.3, 1.5 and 1.7 Mg m^{-3}) (Figure 3.1). The buckets had three drainage holes at the bottom and arranged on raised wooden platforms.

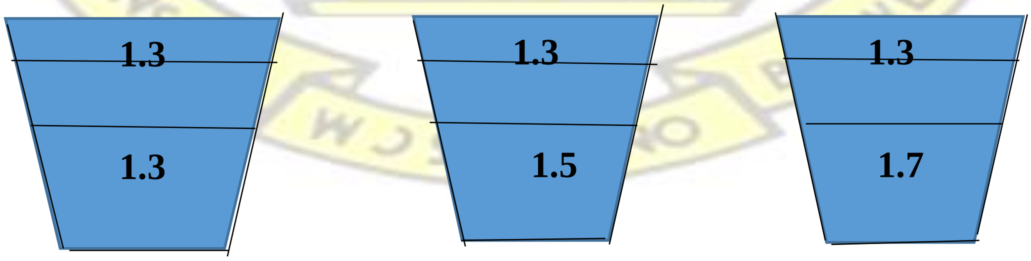

Figure 3.1: Preparation of the buckets used for the experiment

3.7.1.8 Standardization of bulk density

In order to obtain and replicate the desired bulk densities in section 3.6, it was necessary to standardize the method of packing of the soil into the bucket. The volume of the bucket was obtained from the litre graduations (2 L intervals) of the buckets. The mass of soil to be packed into the buckets to give the two-layered soil core was calculated from the equation in section 3.5.14.

Packing of the cores was carried by dropping a 2 kg metal block from a height of 30 cm onto the soil surface which was completely shielded by a wooden plate. For the bulk density of 1.3, 1.5 and 1.7 Mg m^{-3}, half of the requisite air-dried soil was packed into the bottom 8 L volume of the bucket covered with a wooden shield and the metal mass dropped 5, 7 and 9 times respectively.

The shield was then removed and the rest of the soil packed onto the first half using the wooden shelve and the metal mass and drops of 8, 10 and 12 times for the 1.3, 1.5 and 1.7 Mg m^{-3} respectively. The 2 L soil core with a bulk density of 1.3 Mg m^{-3} was imposed over each of the bottom 8 L core using the shield and two drops of the metal block. The mass of soil to attain the 1.3, 1.5 and 1.7 Mg m^{-3} bulk densities was 10.4, 12.0 and 13.6 kg respectively.

3.8 Determination of saturated hydraulic conductivity

A 40 cm^3 metallic cylinders were half filled with soil and the saturated hydraulic conductivities of the layered soils were determined using the modified falling head method. The time taken for every 2 cm drop in the water level in the tube was recorded.

In $\frac{H0}{Ht}$ was plotted against time t (s).

Where

H_0 is the initial height of the water level in the cylinder and Ht,

the final height after the 2 cm drop in the water level.

The slope of the graph is given by $\frac{Ks}{L}$. Where Ks is the saturated hydraulic conductivity and L is the length of the soil column.

Ks= slope × L

3.9. Plants parameters measured

The maize and soybean were harvested 60 days after planting respectively.

3.9.1 Measurement of plant height

A tape measure was used to measure plant heights at 2 weeks interval until harvesting from 11[th] may -8 July, 2013.

Plate 3: Height of maize plants at 4 weeks after planting for the various soil bulk densities

Plate 4: Height of soybean plants at 4 weeks after planting for the various soil bulk densities

3.9.2 Fresh and dry root mass

The fresh root mass was obtained after cutting the soil core into two, comprising a top layer of 1.3 Mg m^{-3} and the bottom layer of the compacted treatments. The total fresh root mass comprised the roots in the top soil core (designated non compacted 1.3 Mg m^{-3}), the bottom core of the compacted treatments (1.3, 1.5. and 1.7 Mg m^{-3}) and the roots that passed between the soil core and the bucket (i.e. roots along the soil core). The latter was obtained by scrapping the roots along the soil core with a knife. The roots in the soil cores were retrieved after washing off the soil over a nest sieves and weighing the clean roots. The dry mass was recorded by weighing after oven drying the sample at 60 ^{0}C for 48 hours.

1.3 Mg m^{-3} 1.5 Mg m^{-3} 1.7 Mg m^{-3}

Plate 5: Inverted soil columns showing maize root growth at different soil bulk densities

3.9.3 Calculation of the relative root mass distribution

The relative root mass distribution (%) at the uncompacted zone, compacted zone and along the soil column was calculated by finding their percentage in relation to the total root mass (uncompacted layer + compacted layer + along the soil column). In relation to the effective root biomass, only the roots at the uncompacted and compacted zones were considered.

3.9.4 Root penetration ratio (RPR)

Root penetration ratio (RPR) is defined as the number of roots that entered the compacted bottom core divided by the number of roots that exited the same core. The number of roots that entered the bottom core was obtained after using a sharp knife to separate the top layer of 1.3 g cm^{-3} from the compacted bottom layer, staining the roots on top of the compacted layer with methylene blue and counting the roots with the aid of a hands lens. The compacted core was then turned upside down and the roots exiting the core counted after staining with methylene blue. For accuracy, the roots that passed between the compacted soil core from the top and the bucket were discarded. Only the roots that were found in the soil were counted and used for the calculation.

3.9.5 Root: shoot ratio

The root shoot ratio was calculated as the total root biomass in the soil core, excluding the roots that passed between the core and the bucket, divided by the total shoot biomass.

3.9.6 Statistical analysis

The data collected were subjected to analysis of variance using GenStat statistical package (12^{th} Edition). The Least significant difference (Lsd) at 5 % was used to compare treatment means.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1. Physico-chemical characteristics of the soil and poultry manure

The results of some chemical and physical properties of the poultry manure and soil used for the experiment are presented in Tables 4.1 and 4.2 respectively Landon‘s (1991) guidelines were used to interpret the results. The soil was a very acidic sandy loam with low levels of organic carbon and nitrogen, moderate phosphorus, calcium and magnesium, and high potassium content (Table 4.2). Such a soil will benefit from soil amendments to improve upon its fertility and productivity.

The poultry manure applied as an amendment had high nitrogen, organic carbon, phosphorus and potassium content (Table 4.1). It was therefore a rich source of nutrients. The high pH of the manure was also envisaged to moderate the very acidic condition of the soil for enhanced nutrient availability and uptake, particularly phosphorus. The C/N ratio of the manure implies a high quality organic material. According to Myers *et al.* (1994), decomposition of materials with Nitrogen content 2 % (or C/N ratio < 25) release mineral N. With an N content of 2.79 %, the poultry manure used in this experiment could potentially release N to enhance the low N status of the soil for improved shoot and root growth.

Table 4.1: Nutrient and organic matter composition of the poultry manure

Soil property	Value
pH (1:10 H_2O)	8.50
Organic carbon (%)	33.92
Total N (%)	2.79
Phosphorus (%)	0.95
Potassium (%)	3.46

C: N ratio	12.16

Table 4.2: Physico-chemical properties of the soil

Soil property	Value
Organic Carbon (%)	1.20
Total N (%)	0.06
pH (1:1 H_2O)	4.02
Available P (mg/Kg)	10.25
Exchangeable cations (cmol/Kg)	
Ca^{2+}	10.40
Mg^{2+}	2.60
K^+	1.10
Na^+	0.80
Particle size distribution (%)	
Sand	61.23
Silt	27.64
Clay	11.13
Textural class	Sandy loam

4.2 Impact of soil compaction on some soil physical properties

Soil physical properties have significant impact on the growth and yield of crops. This includes bulk density, porosity, hydraulic conductivity, in-situ soil moisture and availability. Soil compaction was imposed by using increasing levels of bulk density as proxy. Bulk density is therefore used as an indicator of compaction and interchangeably with soil compaction in this discussion to express the effect of the latter on total porosity, aeration porosity and volumetric water content and hydraulic conductivity.

The results (Table 4.3) showed total porosity to range from 39 to 51 % for the bulk density of 1.7 and 1.3 Mg m^{-3} respectively. Thus as expected, increasing bulk density reduced total porosity. From a base value of 51 % at 1.3 Mg m^{-3}, total porosity was progressively reduced by 16 and 24 % at 1.5 and 1.7 Mg m^{-3} respectively (Table 4.3). The reduction in total porosity implicitly had negative impact on the space available for water and air. There is also a reduction in large pores and a shift towards smaller pore sizes which constrains internal drainage and aeration (Marschner, 1995). Besides the reduced total porosity, soil compaction increased mechanical impedance to root growth, reduced soil water movement and availability, nutrient uptake and gas exchange. The latter results in high carbon dioxide and low oxygen concentrations in the soil atmosphere to the detriment of root elongation (Asady *et al*., 1985; Barraclough and Weier, 1998; Drewry *et al*., 2000; Mckenzie, 2010). These observations are indicative of the implications of the results of this study (Table 4.3).

The reduction in total porosity was accompanied by decreases in aeration porosity. Using the values at 1.3 Mg m^{-3} as a base, the respective reduction of the measured variables at 1.5 and 1.7 Mg m^{-3} were 26 and 28 % for field capacity moisture content; 16 and 55 % for aeration porosity; and 0.0 and 83 % for saturated hydraulic conductivity (Table 4.3). Aeration porosity was more sensitive to soil compaction than total porosity. At a value of 8.6 %, air-filled porosity at the 1.7 Mg m^{-3} was below the 10 % critical value suggested by Gupta and Allmaras (1987) for adequate root growth. As observed by Asady *et al*. (1985), this would impede gaseous diffusion, particularly oxygen and create an unfavourable environment for root growth.

The reduced field capacity (FC) moisture content as a result of compaction imply a reduction in moisture availability for plant growth since FC is considered the upperlimit of soil moisture retention. The results (Table 4.3) have further shown that as total porosity decreased with increasing compaction, so did saturated hydraulic conductivity, particularly at the 1.7 Mg m^{-3}. Hillel (1998) pointed out that the rate of water uptake from a given volume of soil depends on both hydraulic conductivity and the difference between the average water potential of the soil and root. Any restriction on water movement and availability would therefore affect, not only water uptake, but nutrient uptake by mass flow. The above negative impacts on soil physical properties are indicative of the constraints soil compaction can impose on the soil as a favourable medium for crop growth and yield.

Table 4.3: The impact of bulk density on some soil physical properties

Bulk Density (Mg m^{-3})	Porosity (%)	Gravimetric water content (θg)	Air-field Porosity (fa) (%)	Saturated Hydraulic conductivity (cm h^{-1})	Volumetric water content (θv) (%)
1.3	51	24.8	18.8	21.6	32.2
1.5	43	19.6	15.5	21.6	27.5
1.7	39	17.9	8.6	3.6	30.4

4.3 The impact of soil compaction and amendment and their interaction on the growth and biomass yield of maize and soybean

The growth and yield of crops are the result of the product of their genetic make-up and environmental factors. In this section, the results of the impact of soil compaction and amendments and their interaction on the growth and biomass yield of maize and soybean are presented and discussed. The plant parameters studied were plant height, root and shoot biomass, as well as root: shoot ratio and root penetration ratio.

4.3.1. Plant height

The analysis of variance showed soil compaction and amendments to significantly ($p < 0.05$) influence the plant height of maize and soybean (Tables 4.4, 4.5 and 4.6). Plant height used as an indicator of growth of both crops, generally followed the normal growth curve of plants with time, increasing from 7 to 60 days after planting (DAP) at which time the experiment was terminated.

The impact of soil compaction on plant height at 60 DAP is presented in the Table 4.4. The mean height at harvest ranged from 76.83 to 124.92 cm under bulk density of 1.7 and 1.3 Mg m^{-3} respectively. The corresponding values for soybean were 31.83 and 45.50 cm. In all cases the differences among the 3 level of bulk density were significant ($P < 0.05$). A comparison of plant height at 1.3 Mg m^{-3} as base value, showed a progressive reduction of 20 and 38 % for maize and 15 and 30 % for soybean at 1.5 and 1.7 Mg m^{-3} respectively. Between the latter two bulk densities, plant height reduction was 23 and 18 % for maize and soybean respectively.

Muhammad *et al.* (2012) observed that plant height is a genetic characteristic which is modified by environmental factors at the active growth stages. The results have indicated that increasing soil compaction significantly ($P < 0.05$) reduced the height of maize and soybean with the former being more sensitive than the latter to compaction. The reduction in plant height could be due to factors that limited cell elongation which include impedance to root growth, poor soil aeration and low water and nutrient uptake as similarly reported by several authors (Asady *et al.*, 1985; Lowery and Schuler, 1991).

Table 4.4: Impacts of soil compaction on the plant height of maize and soybean

Bulk Density (Mgm^{3})	Maize (cm)	Soybean (cm)
1.3	124.92	45.50
1.5	99.58	38.67
1.7	76.83	31.83
Lsd (5 %)	4.05	1.74

Lsd: least significant difference

The productivity of soil depends not only on its physical properties but chemical and biological properties. The application of mineral fertilizers and poultry manure significantly ($P < 0.05$) increased the height of both maize and soybean (Table 4.5). The plant height of maize (Table 4.5) followed the trend of NPK > poultry manure > ½ poultry manure + ½ NPK > Control with a range of 97 to 105 cm under Control and NPK fertilizer respectively. The differences between NPK and both Control and half rates were significant as well as that between the Control and poultry manure. However, the height difference between poultry manure and both half rates

(integrated application) and NPK were not significant.
In the latter, the NPK recorded the greatest plant height in contrast to poultry manure (PM) in the former. Plant height of soybean was thus in the order poultry manure > ½ PM + ½ NPK > NPK >Control with a range of 33 to 42 cm for the Control and PM respectively. Significant differences ($P < 0.05$) were observed between the Control and all the soil amendments; and between PM and both NPK and half rates.

The results as indicated section 4.4 showed that soil fertility improvement through mineral fertilizer and poultry manure application is essential for the growth of the test crops and a better expression of their potential genetic height. Under these conditions, more nutrients are made available for uptake and for the needed metabolic activities for cell elongation and growth.

An examination of the relative root distribution (Table 4.16) under the various soil amendments showed that in the uncompacted top layer, roots were greater under NPK than poultry manure for Maize. Potential nutrient and water uptake for metabolic activities and stem elongation would therefore be expected to be greater under NPK than PM, hence the recorded greater height under the former. In general, relative root distribution of soybean in the uncompacted top layer was greater than maize under all the treatments and 21 % more than maize under PM. Beneficial effects of the manure (other than nutrients) such as soil moisture storage and availability could account for the greater soybean height recorded under all treatments that incorporated poultry manure than NPK. This is indicative of the benefits of integrated plant nutrition involving the combination of mineral fertilizer and poultry manures. Similar observations have been reported by Law-Ogbomo and Law-Ogbomo (2009) and Obidiebube *et al.* (2012).

Table 4.5: Impacts of soil amendments on the plant height of maize and soybean

Amendments	Maize (cm)	Soybean (cm)
Control	97.00	33.11
poultry Manure	100.67	42.00
NPK Fertilizer	105.33	38.11
½ Poultry Manure + ½ NPK Fertilizer	98.78	41.44
Lsd (5 %)	4.68	2.01

Lsd: least significant difference, P: (probability)

The interaction effect of soil amendment and bulk density significantly ($P< 0.05$) affected the height of maize but not soybean (Table 4.6). Application of soil amendments at all levels of soil compaction tended to enhance plant height relative to compacted soil without amendments. The plant height of both crops at soil bulk density of 1.3 and 1.5 Mg m^{-3} was ameliorated more under NPK than poultry manure and ½

PM + ½ NPK. However, at 1.7 Mg m^{-3}, the latter treatments were more effective than NPK. The beneficial effects of organic matter on soil physical properties, such as bulk density and porosity may be implicated in these observations.

Table 4.6: Interaction effect of soil amendments and different soil compaction levels on plant height of maize

Amendment *bulk density (Mg m^{-3})	Maize (cm)
Control x1.3	123.67
Control x 1.5	90.33
Control x1.7	77.00
NPK Fertilizer x 1.3	132.00
NPK Fertilizer x 1.5	110.67
NPK Fertilizer x 1.7	73.33
PM x 1.3	122.67
PM x 1.5	100.67
PM x 1.7	78.67
½ PM + ½ NPK fertilizer x 1.3	121.33
½ PM + ½ NPK fertilizer x 1.5	96.67
½ PM + ½ NPK fertilizer x 1.7	78.33
Lsd (5 %)	8.10

Lsd: least significant difference,

4.3.3. Root biomass

The results of this study (Table 4.7, 4.8 and 4.9) showed that soil compaction and amendments and their interactions significantly ($P < 0.05$) affected root biomass, distribution and penetration ratio. In this discussion, total effective root biomass refers to the sum of the mass of roots retrieved from the uncompacted and compacted soil core excluding those between the inner wall of the bucket and soil core (i.e. roots along the periphery of the soil core).

Total effective dry root biomass of maize (Table.4.7) ranged from 27.64 and 67.87 g/plant for the 1.7 and 1.3 Mg m^{-3} respectively. The differences in root biomass among the 3 levels of compaction were significant ($P < 0.05$). The reduction in root biomass as bulk density increased from 1.3 to 1.5 and 1.7 Mg m^{-3} was 50 and 59 % respectively.

In the case of soybean, total dry root biomass (Table 4.7) ranged between 8.17 and 10.49 g/plant for the 1.5 and 1.3 Mg m^{-3} respectively following a trend of 1.3> 1.7> 1.5 Mg m^{-3}. Root biomass at 1.3 Mg m^{-3} was significantly ($p < 0.05$) greater than those of 1.5 and 1.7 Mg m^{-3} which did not significantly differ from each other. The reduction in total root biomass relative to that of the 1.3 Mg m^{-3} was 22 and 14 % for the 1.5 and 1.7 Mg m^{-3} respectively

Table 4.7: Impact of soil compaction levels on the effective root biomass of maize and soybean

Treatments	Effective root biomass (g/plant)	
Bulk density (Mg m^{-3})	Maize	Soybean
1.3	67.87	10.49
1.5	33.98	8.17
1.7	27.64	9.05
Lsd (5 %)	2.34	1.73

Lsd: least significant difference, P: (probability)

The magnitude of reduction in total root biomass indicated that the negative impact of soil compaction was greater on maize (a monocot) than soybean (a dicot) roots. A similar observation was reported by Materechera *et al.* (1991). Chen and Weil (2009) also found that rye toots decreased more rapidly than rapeseed roots as soil strength increased.

As indicated in Section 4.2, soil compaction reduced total porosity, air–filled porosity and hydraulic conductivity, with their inferred increase in mechanical impedance, reduced oxygen, water and nutrient uptake. It is therefore not surprising that significant reductions in total root biomass was recorded as soil compaction increased from 1.3 Mg m^{-3} through 1.5 to 1.7 Mg m^{-3}.

In order to sustain crop growth and yield in compacted soils, ameliorative strategies to address the adverse impacts of soil compaction on root growth and biomass production need to be developed. In this context, the application of adequate amounts of soil amendments has been found to offset the negative effects of soil compaction on root growth (Hakansson and Lipiec 2000; EPA, 2007; Mackay *et al.*, 2010).

The results of this study (Table 4.8) showed the application of soil amendments to significantly influence the total root biomass of both maize and soybean. Total dry root biomass of maize was in the order of NPK > ½ PM + ½ NPK > PM> Control with a range of 24.34 to 63.99 g/plant for the Control and NPK, respectively. All the soil amendments significantly ($p < 0.05$) out yielded the Control. Root biomass of the NPK was significantly greater than those of PM and ½ PM + ½ NPK which did not differ significantly. The percentage increase in root biomass, using the Control value as a base was 42, 43 and 62 under PM, ½ PM + ½ NPK and NPK respectively.

In the case of soybean, total biomass ranged from 5.83 to 12.42 g/plant with a similar trend as that of maize. From a base value of 5.83 g/plant, NPK, ½ PM + ½ NPK and PM increased root biomass by 53, 38 and 37 % respectively. The impact of the application of soil amendments in ameliorating soil compaction for root biomass yield was therefore greater for maize than soybean.

Table 4.8: Impact of soil amendments on the effective root biomass of maize and soybean

Treatments	Root biomass (g/plant)	
Bulk density ($Mg\ m^{-3}$)	Maize	Soybean
1.3	67.87	10.49
1.5	33.98	8.17
1.7	27.64	9.05
Lsd (5 %)	2.34	1.73

The development of extensive root system enhances the ability of plants to abstract nutrients and water from the soil. The constraining impact of soil compaction on root growth therefore tends to limit the availability of water and nutrients for satisfactory plant growth and yield (Raza *et al*., 2005; Chen and Weil, 2011). The results of the study have clearly demonstrated the ameliorative impact of soil amendments in reducing the adverse effects of soil compaction on root biomass yield. The provision of readily available nutrients favoured root development and vigour for effective nutrient and water uptake from the soil. The subsequent translocation of the nutrients and water to the shoot may underscore significant increases in shoot biomass.

The ameliorative impact of soil amendments on soil compaction effects on root growth became more evident when the soil amendment and compaction interactions were examined. The results (Table 4.9) showed that at each level of soil compaction, all the soil amendments significantly increased total root biomass over the Control with no amendment. The increases in root biomass were greater in maize than soybean.

Table 4.9: Interaction effect of soil amendments and different compaction levels on effective root biomass of maize and soybean

Amendment *bulk density ($Mg\ m^{-3}$)	Maize (g/plant)	Soybean (g/plant)
Control x1.3	27.97	5.58
Control x 1.5	25.23	3.46
Control x1.7	19.81	8.46
NPK Fertilizer x 1.3	105.55	13.72
NPK Fertilizer x 1.5	50.13	11.61
NPK Fertilizer x 1.7	36.29	11.93
PM x 1.3	74.73	11.25
PM x 1.5	27.31	7.25
PM x 1.7	23.67	9.40
½ PM + ½ NPK fertilizer x 1.3	63.23	11.42
½ PM + ½ NPK fertilizer x 1.5	33.24	10.35
½ PM + ½ NPK fertilizer x 1.7	30.80	6.43
Lsd (5 %)	5.88	3.47

Lsd (least significant difference), p (probability)

4.3.3 Root Distribution and Penetration Ratio

4.3.3.1 Root distribution

In the presence of only one compacted layer, as may occur under conventional tillage and simulated in this study, a reduction in root growth in the compacted zone is often compensated for by higher growth rates in loose soil above or below the compacted zone (Marschner, 1995). The percentage relative root mass was used to assess root distribution of the total effective root mass in the uncompacted top soil (1.3 $Mg\ m^{-3}$) and the compacted soil core. The results showed soil compaction and amendments, as well as their interaction, to distinctly influence the roots distribution of maize and soybean. The impact of increasing soil compaction on both crops was manifested in a greater accumulation of root biomass in the top uncompacted soil than the compacted soil cores. The mean relative root biomass distribution of maize and soybean as affected by soil compaction are presented in Table 4.10 and 4.11. In maize, the relative root biomass distribution in the uncompacted soil layer ranged from 69.60 to 90.78 % for the 1.3 and 1.7 Mg m^{-3} respectively with a trend of 1.7> 1.5> 1.3 Mg m^{-3} (Table 4.10). Increasing bulk density therefore resulted in more root biomass accumulation in the relatively loose top soil. The converse was true in the compacted soil cores with values between 9.22 % for the 1.7 Mg m^{-3} and 30.40 % for the 1.3 Mg m^{-3} in an order of 1.3> 1.5> 1.7 Mg m^{-3} (Table 4.10). This implies less root accumulation in the compacted core as the bulk density of the compacted layer increased. These trends were similar for the soybean. The respective range of relative root biomass for the 1.3 and 1.7 Mg m^{-3} in the uncompacted and compacted soil was 69.59 to 90.77 % and 30.4 to 9.2 % (Table 4.11). The characteristic distribution of roots in compacted soil presented in this study has similarly been reported by Marschner (1995) and Lipeic *et al.* (2003). Chen and Weil (2009) also observed greater root proliferation in the loose layer above the compacted layer for rapeseed and rye.

Table 4.10: Relative root mass of maize as affected by soil compaction in the compacted and uncompacted layers

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)
1.3	69.60	30.40
1.5	72.36	2.71
1.7	90.78	9.22

Table 4.11: Relative root mass of soybean as affected by soil compaction in the compacted and uncompacted layers

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)
1.3	69.59	30.41
1.5	72.40	27.60
1.7	90.77	9.23

This pattern of root biomass distribution is ascribed mainly to the magnitude of mechanical impedance in the soil. When soils are compacted, the bulk density is increased and the number of larger pores is reduced while smaller pores increase. In such situations, the forces of roots necessary for deformation and displacement of soil particles for root proliferation increase and readily become limiting with a consequent reduction in root growth. There is also a tendency of roots to grow horizontally/laterally in the uncompacted layer above the compacted soil core (Wolkowski and Lowery, 2008). As pointed out by Marschner (1995) and other authors (Houlbrooke, 1996; Wolkowski and Lowery, 2008; Chen and Weil, 2009), the observed greater root biomass in the uncompacted than compacted soil in this study was viewed as a compensatory response to the increased mechanical impedance and reduced total porosity and aeration porosity associated with compaction of the soil core.

The results further lend credence to the observation of Materechera *et al*. (1991 and 1993**)** that monocot and dicot species respond differently to changes in soil with dicots being better in penetrating compacted soil than monocots. Thus, as indicated earlier, total effective root biomass was more sensitive in maize than soybean to increases in soil compaction with the reduction in the effective root biomass at 1.3 Mg m^{-3} being 50 and 59 % at 1.5 and 1.7 Mg m^{-3} respectively with the corresponding figures for soybean as 22 and 14 %.

Effective root biomass of maize was also more responsive to soil amendments with the percentage increases over the Control (no amendment) being 42, 43 and 62 under PM, ½ PM + ½ NPK and NPK respectively. The corresponding values for soybean were 37, 38 and 53 %. Besides these observations, the results revealed variable impacts of soil amendments on total effective root biomass (compacted + uncompacted root biomass) and their distribution in the compacted and uncompacted layers. While all the soil amendments increased effective root biomass at each level of soil compaction over the control (Table 4.12 and 4.13), variable impacts were recorded in the case of relative root biomass distribution.

In maize, while relative root biomass in the uncompacted soil was increased over that of the Control, it was reduced in the compacted soil (Table 4.12). The increases were 4, 11 and 18 % under PM, ½ PM + ½ NPK and NPK respectively. The corresponding reduction was 6, 15 and 27 %. Implicitly, the decrease in the relative root biomass in the compacted soil core was compensated for by the increased fibrous roots in the uncompacted layer.

In the case of soybean, although the relative root biomass accumulation in the uncompacted soil was relatively greater than that of maize, the application of soil amendments tended to slightly decrease the relative root biomass over that of the Control (Table 4.13). The percentage reduction was 3, 5 and 8 under NPK, ½ PM + ½ NPK and PM respectively. The corresponding increases in the compacted core were 10, 18 and 27 %. The variable characteristic distribution of different rooting systems (fibrous and tap root for maize and soybean) in the soil profile and their response to soil compaction, nutrient and water uptake could have accounted for the observed differences in the relative root biomass distribution in the compacted and uncompacted soil.

Table 4.12: Relative root mass of maize as affected by soil amendments at the compacted and uncompacted layers

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)
Control	56.10	43.89
Poultry manure	58.57	41.42
NPK	68.17	31.82
½ Poultry M.+ ½ NPK	62.75	37.24

Table 4.13: Relative root mass (%) of soybean as affected by soil amendments at the compacted and uncompacted layers

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)
Control	81.07	18.92
Poultry manure	74.25	25.74
NPK	78.88	21.11
½ Poultry M.+ ½ NPK	76.81	23.18

4.3.3.2 Root restriction

The encounter of roots with impeding soil compacted layers results not only in the restrictive root growth and rate of oxygen supply, but induced counter root responses. Apart from growing and spreading horizontally in the loose soil above the compacted zone which deprives them of the full use of moisture and nutrients below this layer, roots tend to follow tortuous path seeking for the path of least resistance (Bengough and Mullins, 1991; Lampurlanes and Cantero-Martinez, 2003). In the field, growth is through available larger interaggregate and biopores greater than root diameter (Cresswell and Kirkegaard, 1995). In pot experiments, as in this study, the growth is through the unrestrictive path between the inner wall of the pot and the compacted soil core. This impacts was assessed by the relative root biomass distribution in the compacted, uncompacted and along the soil core. The relative root biomass was calculated from the total root mass, comprising the sum of the effective root biomass (compacted+ uncompacted) and the root mass along the periphery of the soil core.

The results of the impact of soil compaction on the peripheral root distribution along the soil core are presented in Table 4.14 for maize and Table 4.15 for soybean. The peripheral relative root biomass for maize (Table 4.14) ranged from 27.70 to 39.22 % in the order of 1.7< 1.3< 1.5 Mg m^{-3}. The same trend was observed in soybean with the values ranging between 40.40 and 43.56 % (Table 4.15). The peripheral root distribution increased as bulk density increased from 1.3 Mg m^{-3} to 1.5 Mg m^{-3} and declined at 1.7 Mg m^{-3}. The peripheral root biomass was greater in soybean than maize. The response of the soybean to soil compaction was to induce more root growth in the uncompacted soil and periphery of the soil core than the compacted zone. The same trend was observed in maize except that the magnitude was greater in soybean.

Table 4.14: Relative root mass of maize as affected by soil compaction (%)

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)	Along soil core (%)
1.3	43.94	24.21	31.84
1.5	37.84	22.94	39.22
1.7	42.91	29.32	27.70

Table 4.15: Relative root mass of soybean as affected by soil compaction

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)	Along soil core (%)
1.3	39.46	17.24	43.33
1.5	40.89	15.59	43.56
1.7	54.08	5.50	40.40

The results of the impact of soil amendments on the peripheral root distribution along the soil core are presented in Tables 4.16 and 4.17 for both maize and soybean respectively. The peripheral relative root biomass for maize ranged from 28.96 to 42.72 % in the increasing order of ½ PM + ½ NPK< NPK< PM< Control and 34.24 to 49.60 % in the NPK< ½ PM + ½ NPK< Control < PM for both maize and soybean respectively. In maize the highest peripheral relative root biomass was recorded by the control where no soil amendment was applied and the least value was recorded by ½ PM× ½ NPK (Table 4.16). This indicates the importance of soil amendments in enhancing the magnitude of effective roots. Also, the synergistic effect of both organic and inorganic amendment was evident as ½ PM + ½ NPK performed better than the sole amendments. In soybean, the sole NPK amendment recorded the least value of the peripheral relative root distribution, this also indicates that most of the effective roots produced under the sole NPK penetrated both the compacted and the uncompacted layer (Table 4.17).

Table 4.16: Relative root mass of maize as affected by soil amendments

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)	Along soil core (%)
Control	32.11	25.12	42.72
Poultry manure	38.34	27.12	34.52
NPK	47.36	22.11	30.52

½ Poultry M.* ½ NPK	44.57	26.45	28.96

Table 4.17: Relative root mass of soybean as affected by soil amendments

Treatment Bulk density (Mg m^{-3})	Uncompacted top layer (%)	Compacted/ bottom layer (%)	Along soil core (%)
Control	42.11	9.83	48.08
Poultry manure	56.22	19.49	49.60
NPK	35.93	9.62	34.24
½ Poultry M.* ½ NPK	45.10	13.61	41.32

The compaction x soil amendment interaction in maize (Table 4.18) revealed a tendency of the soil amendments (except ½ PM + ½ NPK fertilizer) to decrease peripheral root growth at 1.3 and 1.5 Mg m^{-3} and an increase at 1.7 Mg m^{-3}. The ½ PM + ½ NPK fertilizer increased the peripheral root biomass of maize as soil compaction levels increased. Implicitly, the values of the peripheral root biomass represent the proportion of the total root mass presenting ineffective root surfaces for nutrient and water uptake which obviously would constrain shoot growth and biomass yield. These confounding impacts are often neglected in most pot experiments, yet they are important in the interpretation of results and potential extrapolation to field conditions.

An additional observation in this study was the accumulation of loose roots at the base of the soil core, apparently originating from the peripheral root growth. These are indicative of root volume restriction (_bonsai‘ effect) which tends to inhibit shoot growth caused by limited nutrients and water supply to the shoots with the magnitude of reduction in root and shoot dry matter increasing with decreasing pot size. These impacts were taken into consideration in the assessment of root penetration ratio and root: shoot ratio.

Table 4.18: Interaction effect between soil amendments and different compaction levels on relative root mass of maize

Amendment x bulk density ($Mg\ m^{-3}$)	Uncompacted top layer (%)	Compacted/ bottom layer (%)	Along soil core (%)
Control x1.3	27.29	22.78	49.94
Control x 1.5	28.81	25.05	46.10
Control x1.7	49.25	30.59	20.15
NPK Fertilizer x 1.3	50.69	20.69	28.60
NPK Fertilizer x 1.5	44.41	20.23	35.21
NPK Fertilizer x 1.7	41.97	29.82	28.92
PM x 1.3	42.77	26.57	30.64
PM x 1.5	28.86	24.29	47.23
PM x 1.7	39.28	33.47	27.23
½ PM + ½ NPK fertilizer x 1.3	44.62	28.18	27.18
½ PM + ½ NPK fertilizer x 1.5	45.92	23.77	30.29
½ PM + ½ NPK fertilizer x 1.7	43.05	24.39	39.98

4.3.4 Root penetration ratio

The results of the impact of soil compaction and soil amendments and their interactions are presented in Tables 4.19, 4.20 and 4.21. The effect of soil compaction (Table 4.19) showed a general decrease in root penetration ratio (RPR) with increasing bulk density. At a base of 0.33, RPR of maize was reduced by 12 % at 1.5 Mg m^{-3} and 9 % at 1.7 Mg m^{-3}. With values ranging from 0.29 to 0.33, the differences were not significant ($p> 0.05$). In the case of soybean (Table 4.19) RPR varied from 0.14 to 0.31 for the 1.7 and 1.3 Mg m^{-3} respectively. While there was no significant difference in the values at 1.3 and 1.5 Mg m^{-3}, the latter values were significantly greater than that at 1.7 Mg m^{-3}. The percentage reduction in RPR at 1.7 Mg m^{-3} was 13 and 55 relative to that at 1.5 and 1.3 Mg m^{-3} respectively. These results indicated that the impact of soil compaction on root proliferation was more severe on soybean than maize.

Table 4.19: Root penetration ratio of maize and soybean on soil of different compaction levels

Bulk density (Mg m^{-3})	Maize	Soybean
1.3	0.33	0.31
1.5	0.29	0.27
1.7	0.30	0.14
Lsd (5 %)	0.06	0.06

Lsd (least significant difference)

One of the most important factors which affects roots penetration is soil bulk density (Unger and Jones, 1998). High bulk densities adversely affects roots elongation and proliferation within a soil profile (Bengough and Mullin, 1990). At the higher bulk density, 1.7 Mg m^{-3}, the soil became so dense that root penetration through the compacted zone was impeded. Thus, fewer roots were able to exit the compacted soil core. This is not surprising since in sandy loams, as was used in this experiment, bulk densities in the range of 1.6 and 1.8 Mg m^{-3} restricts root penetration (Landon, 1991). According to NRC (1993), when the bulk density of soil increase to a critical level, root penetration is restricted and root growth is reduced. Beyond the critical level, roots are unable to penetrate the soil and root growth is prevented. These changes affect the productivity of the plant and can lead to lower yield and/or higher cost of production. At the bulk density of 1.7 Mg m^{-3}, the maize and soybean were stunted and drought stressed. Limited root penetration on compacted soil have been found to aggravate the effects of drought in reducing soybean yield (Buttery *et al*., 1998). According to Marschner (1995), for a given soil bulk density, the mechanical impedance increases as the soil dries. This is due to increased particle mobility indicating an increase in the forces required to displace and deform soil particles, and resultant suppression of root elongation. This, in turn, could restrict water and nutrient uptake and poor plant growth and yield.

The impact of soil amendments (Table 4.20) was an increase in RPR over the Control. The adverse impact of soil compaction was therefore ameliorated by the application of soil amendments. In the case of maize (Table 4.20), RPR ranged from 0.22 to 0.39 with a decreasing trend of NPK> ½ PM+ ½ NPK> PM> Control. NPK recorded significantly ($P < 0.05$) greater RPR than all other amendments and the Control with a percentage increase over the latter being 46 %. The RPR of the PM and ½ PM+ ½ NPK were also significantly ($P< 0.05$) greater than the Control with increment in the range of 27-29 %.

In soybean, (Table 4.20), RPR varied between 0.14 and 0.28 in the order of NPK=½ PM+ ½ NPK>PM> Control. However, the RPR of all the amendments did not differ significantly ($p> 0.05$) from each other but were significantly greater than the Control with an increment of 46-50 %.

Table 4.20: Impact of soil amendments on root penetration ratio of maize and soybean

Treatment Bulk density (Mg m^{-3})	Maize	Soybean
Control	0.22	0.14
Poultry manure	0.30	0.26
NPK	0.39	0.28

½ PM.* ½ NPK	0.31	0.28
Lsd (5 %)	0.07	0.07

Table 4.21: Impact of soil amendments and different compaction levels on total root penetration ratio of maize

Amendment (g/plant)*bulk density(Mg m^{-3})	Maize
Control x1.3	0.27
Control x 1.5	0.23
Control x1.7	0.15
NPK Fertilizer x 1.3	0.33
NPK Fertilizer x 1.5	0.42
NPK Fertilizer x 1.7	0.33
PM x 1.3	0.30
PM x 1.5	0.20
PM x 1.7	0.40
½ PM + ½ NPK fertilizer x 1.3	0.33
½ PM + ½ NPK fertilizer x 1.5	0.30
½ PM + ½ NPK fertilizer x 1.7	0.30
Lsd (5 %)	0.13

The compaction x amendments interaction significantly ($P< 0.05$) influenced RPR of maize but not soybean (Table 4.22). At each level of compaction, each of the soil amendments improved RPR but more so by NPK. The addition of soil amendments provided readily available nutrients to the roots thereby improving root growth and vigour for enhanced penetration of the compacted soil. Under such conditions, uptake of water and nutrients is also improved for the benefit of shoot growth and biomass yield.

4.3.5 Dry shoot biomass yield

The previous discussion has revealed the impacts of soil compaction and amendments and their interactions on root biomass yield and other root parameters of maize and soybean. In consonance with the tendency of root and shoot systems to maintain a balance (Hartmann *et al*., 1988) and their inter-dependency (Kramer, 1969), the effects of the above factors on shoot biomass yield were assessed.

Soil compaction significantly ($P < 0.05$) influenced the shoot biomass of maize and soybean (Table 4.22). In the case of maize, shoot biomass ranked as 1.3>1.5>1.7 Mg m^{-3} with a range of 69.95 to 115 g/plant for the 1.7 and 1.3 Mg m^{-3} respectively. The difference among the treatments were significant ($P < 0.05$). Shoot biomass therefore decreased with increasing soil bulk density as similarly reported by several authors (Gediga, 1991; Lowery and Schuler, 1991; Motavalli *et al*., 2003). The reduction in shoot biomass of maize as bulk density increased from 1.3 Mg m^{-3} to 1.5 and 1.7 Mg m^{-3} was 20 and 40 % respectively.

The soybean followed the above trends but in terms of magnitude. Shoot biomass of soybean (Table 4.22) varied from 32.66 to 69.84 g/plant for the 1.7 and 1.3 Mg m^{-3} respectively with significant differences ($P < 0.05$) among the treatments. The reduction in shoot biomass, using that of 1.3 Mg m^{-3} as a base gave 17 and 57 % at the 1.5 and 1.7 Mg m^{-3} respectively. The adverse impact of soil compaction on shoot biomass in both soybean and maize was greater at 1.7 Mg m^{-3} with the former being more.

The response of maize and soybean shoot biomass to increasing bulk density appears to suggest optimum bulk density for shoot biomass production to be 1.3 Mg m^{-3} with a range of 1.3 to < 1.5 Mg m^{-3}. The magnitude of response, however seem to be influenced by the stage of growth as well as the fertility level of the soil. In this context, Ocloo (2011) found the ideal range of bulk density for the growth of maize and soybean seedlings to be 1.1 to 1.5 Mg m^{-3} with 1.3 Mg m^{-3} as the most preferable in terms of shoot biomass yield and root penetration ratio. Beutler and Centurion (2004), on the other hand, reported that soybean growth and yield started to decline beyond a bulk density of 1.36 Mg m^{-3} on soil with no fertilizer and 1.48 Mg m^{-3} on soils that received fertilizer treatment.

The reduction in shoot yield with increasing soil compaction may be attributed to one or a combination of the adverse conditions that were created in the soil environment. In this study, increasing soil compaction increased soil bulk density, reduced both total and aeration porosity with the later below the artificial critical level of 10 % for favourable gaseous exchange at the 1.7 Mg m^{-3}. The implication of these conditions include increased impedance to root growth, which in turn, reduces the requisite water and nutrient uptake for satisfactory root and shoot growth. The reduced aeration porosity and its negative impact on gaseous exchange resulting in reduced oxygen supply accumulation of carbon dioxide could adversely affect root growth and indirectly affect shoot growth. Similar observations have been reported by several authors (Asady *et al*., 1985; Marschner, 1995; Ishag *et al*., 2001; Ocloo, 2011; Muhammad *et al*., 2012). Efforts to increase and sustain crop growth and yield on compacted soils include breaking compacted layers through ripping by tines and subsoiling (Raza *et al*., 2005; Mckenzie, 2010; Crush and Thom, 2011); biological drilling (William and Weil, 2004); and ameliorating the negative impact of compaction through the application of mineral and organic sources of nutrients to enhance vigorous root growth (Beutler and Centurion, 2004; EPA, 2007; Mackay *et al*., 2010).

Table 4.22: Impact of soil compaction on shoot biomass production of maize and soybean

Bulk Density ($Mg\ m^{-3}$)	Maize (g/plant)	Soybean (g/plant)
1.3	115.72	69.84
1.5	92.62	57.70
1.7	69.95	32.66
Lsd (5 %)	4.42	1.63

In this study, the impact of soil amendments on the growth and yield of maize and soybean and in ameliorating the adverse effects of soil compaction on shoot biomass was assessed. All the soil amendments (Table 4.23) significantly increased the shoot biomass of maize and soybean over the Control. Shoot biomass of maize (Table 4.23) ranged from 78.43 and 109.05 g/plant for the Control and NPK respectively with a trend of NPK> ½ PM+ ½ NPK> PM> Control. In all cases, the differences among the treatments were significant ($P < 0.05$). The increase of shoot biomass over the Control were 28, 18 and 10 % under NPK, ½ PM+ ½ NPK, and PM respectively.

The shoot biomass of soybean (Table 4.23) followed the same trend as maize with yield ranging between 35.56 and 67.91 g/plant. Yield increments over the Control were 48, 41 and 28 % under NPK, ½ PM+ ½ NPK, and PM respectively. The magnitude of response to soil amendments was greater in soybean than in maize.

The soil compaction x amendments interaction (Table 25) significantly influenced shoot biomass yield of maize and soybean. It revealed the magnitude of the soil amendments in increasing the biomass yield at each level of soil compaction. The depressive effect of soil compaction on shoot yield was therefore ameliorated by soil amendments.

Table 4.23: Impact of soil amendments on shoot biomass yield of maize and soybean

Amendments	Maize (g/Plant)	Soybean (g/Plant)
Control	78.43	35.56
NPK Fertilizer	109.05	67.91
Poultry Manure	87.39	49.64
½ PM * ½ NPK	96.17	60.50
Lsd (5 %)	5.11	1.89

Table 4.24: Interaction effect of soil amendments and different compaction levels on shoot biomass yield of maize

Amendment * bulk Density (mg m^{-3})	Maize (g/plant)	Soybean (g/plant)
Control X 1.3	111.02	48.90
Control X 1.5	91.55	41.67
Control X 1.7	59.60	16.10
NPK Fertilizer X 1.3	133.23	87.65
NPK Fertilizer X 1.5	104.48	68.12
NPK Fertilizer X 1.7	89.43	47.97
PM x 1.3	92.87	64.42
PM x 1.5	77.42	57.90
PM x 1.7	65.00	26.59
½ PM + ½ NPK Fertilizer X 1.3	125.75	78.39
½ PM + ½ NPK Fertilizer X 1.5	97.02	63.13
½ PM + ½ NPK fertilizer x 1.7	65.76	39.98
Lsd (5 %)	8.85	3.27

The percentage increment by soil amendment in shoot yield at each level of soil compaction, using the yield under Control as the standard is presented (Table 4.25). In both crops, the impact was greatest under NPK and at the highest level of soil compaction. The magnitude of impact was greater on soybean than on maize as indicated earlier by the main effect of soil amendments. The effect of poultry manure was also greater at the 1.7 Mg m^{-3} than the remaining bulk densities.

The results have shown the need for soil amendments in enhancing shoot biomass yield but more so on compacted soils and for soybean cultivation. The need for mineral fertilizer in enhancing crop growth on soils low in nitrogen and soil organic matter has also been demonstrated, even in the case of soybean contrary to the general notion that nitrogen-fixing legumes do not need fertilizers, especially, N. On such soils, as was used in this experiment, N would be needed. In this context, integrated plant nutrition, using combined mineral and organic sources of nutrients could be an advantage considering the near addictive effects of the ½ NPK+ ½ PM on shoot biomass yield observed in this study.

In soybean, the calculated sum of half biomass yield of sole NPK and PM was 78.2, 62.95 and 36.3 g/plant at the 1.3, 1.5 and 1.7 Mg m^{-3} respectively. The corresponding yields of the ½ NPK+ ½ PM were 78.39, 63.13 and 39.98 g/plant. In maize, the sum of the sole NPK and PM was 113.06, 90.95 and 77.22 g/plant at the 1.3, 1.5 and 1.7 Mg m^{-3}. The corresponding yields of the ½ PM+ ½ NPK were 125.75, 97.02 and 65.76 g/plant.

Table 4.25. Percentage increment in shoot biomass yield by soil amendments at each level of soil compaction

Soil amendments	Soil compaction level (Mg m^{-3})		
	1.3	1.5	1.7

	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)
Control	-	-	-	-	-	-
NPK	17	44	12	39	33	66
PM	-	24	1	28	23	39
½ PM+ ½ NPK	18	38	6	34	9	60

4.3.6 Root: shoot ratio

The inter-dependence between roots and shoots also manifests in the magnitude of root: shoot ratio which is indicative of the dry matter incorporated in each of them. Kramer (1969) observed the paucity of information on this partitioning of photosynthate and alluded it to the difficulty in obtaining entire root system. Because of this, such information is often neglected in in most crop productivity studies, yet it is needed for the accurate measurement of net productivity. The dependence of roots on shoots for their carbohydrate supply implies that any factor that has a depressive effect on shoot biomass would equally affect root biomass yield. Accordingly, the impact of soil compaction and soil amendments on root: shoot ratios of maize and soybean were assessed.

The results (Table 4.26 and 4.27) showed soil compaction and amendments to significantly influence root: shoot ratio. The impact of soil compaction (Table 4.26) showed root: shoot ratio to range from 0.37 to 0.59 for maize and 0.14 to 0.27 for soybean. In maize, the significantly greater ratio at 1.3 Mg m^{-3} was reduced by 37 % at the 1.5 Mg m^{-3}. In soybean, the reduction was 7 %. The implication is that, at the lower range of bulk density, 1.3 to 1.5 Mg m^{-3}, the reduction in root biomass resulting from increasing compaction is greater than that in the shoot biomass. The tendency was for root: shoot ratio to decrease. This is evidenced in this study by a reduction in shoot and root biomass yield of maize by 20 % and 50 % respectively when bulk density increased from 1.3 to 1.5 Mg m^{-3}. The corresponding decrease in soybean was 17 and 22 %.

However, beyond 1.5 Mg m^{-3}, the tendency was for root: shoot ratio to increase with increasing soil compaction. Increasing soil compaction from 1.5 to 1.7 Mg m^{-3} increased root: shoot ratio by 7 and 48 % in maize and soybean respectively. The underlying reason in this case was that the reduction in shoot biomass, 24 and 43 % in maize and soybean, was greater than the decreases in their corresponding root biomass of 19 and 10 % at the 1.7 Mg m^{-3}. According to Marschner (1995), the root cap, as a sensor of stress due to the restriction of root growth in the compacted soil, is implicit in this process. It triggers the accumulation of Abscicic Acid (ABA) in the roots which is transported to the shoot. As a ‗stress hormone' ABA depresses shoot growth by inhibiting cell extension in shoot tissue and inducing stomatal closure. This area of research has received very limited research attention. Yet, studies on the interdependence of shoots and roots in many ways and the role of phytohormones in their response to various stress conditions in the rooting zone are required to inform the development of strategies for sustainable plant growth and yield. Such stresses include moisture, nutrients, drought and compaction.

It is however worthy to note the main findings of the impact of soil compaction on root: shoot ratio. The magnitude and direction of change in root: shoot due to increasing soil compaction depend on the level of compaction and the type of crop. At the lower range of soil compaction, 1.3 to 1.5 Mg m^{-3} in this work and 1.1 to 1.5 Mg m^{-3} in Ocloo (2011), root: shoot ratio decreased with increasing compaction. Beyond these ranges 1.5 to 1.7 Mg m^{-3} in this study and 1.5 to 1.9 Mg m^{-3} (Ocloo, 2011) root: shoot ratio increased with increasing soil compaction.

Table 4.26: Impact of soil compaction on root: shoot ratio of maize and soybean

Bulk Density (Mg m^{-3})	Maize (per plant)	Soybean (Per Plant)
1.3	0.59	0.15
1.5	0.37	0.14
1.7	0.40	0.27
Lsd (5 %)	0.04	0.08

Lsd (least significant difference)

The study has amply shown soil amendments to ameliorate the adverse impact of soil compaction on root and biomass yield. This, obviously, has implications for the magnitude of the root: shoot ratio, which is the dry matter (photosynthate) portioned into the root as a proportion of that in the shoot. Consequently, the impact of soil amendments and its interaction with soil compaction on root: shoot ratio was assessed.

The soil amendments applied significantly (P< 0.05) influenced the root: shoot ratio of maize but not soybean (Table 4.27). All the soil amendments increased root: shoot ratio in both maize and soybean over the Control. In the maize, the root: shoot ratio was in a decreasing order of NPK> PM> ½ PM+ ½ NPK > Control with a range of 0.31 to 0.59 for the Control and NPK respectively (Table 4.27). In the soybean, the range was 0.16 to 0.19 for the Control and PM with a trend of PM> NPK> ½ PM+ ½ NPK= Control (Table 4.27). The increment in the root: shoot ratio indicated that the application of the soil amendments increased biomass of both root and shoot but more so in the former as indicated by the results. The increment in root biomass of maize were 62, 43 and 42 % under NPK, ½ PM+ ½ NPK and PM respectively. The corresponding increases in shoot biomass were 28, 18 and 10 %. In soybean, the increments in the root and shoot biomass were 53 and 48 % under NPK, 37 and 28 % under PM, and 38 and 41 % under ½ PM+ ½ NPK.

Table 4.27: Impact of soil amendments on root: shoot ratio of maize and soybean

Amendments	Maize (g/Plant)	Soybean (g/plant)
Control	0.29	0.50
NPK Fertilizer	0.56	0.25
Poultry Manure	0.51	0.27
½ PM X ½ NPK	0.44	0.23
Lsd (5 %)	0.05	0.20

Lsd (least significant difference)

A similar trend was observed under the amendment x compaction interaction (Table 4.28). In all cases, soil amendment significantly ($P < 0.05$) increased the root: shoot ratio at each level of soil compaction. However, under each amendment x compaction level, root: shoot ratio tended to decrease with increasing bulk density in maize contrary to the observed increases in root: shoot ratio with increasing bulk density under the main effect of soil compaction. The latter scenario was observed in the case of soybean. The direction of change in the magnitude of root: shoot ratio is therefore not as simple. It seems to be influenced by the type of crop (cereal legume) and the confounding effects of factor interactions on the relative increases/reduction in shoot and root growth. This can be viewed in the simple general observation that under abundant supply of essential nutrients, particularly N and P, root growth is stimulated but more so in shoot in fertile than infertile soil (Marschner, 1995; Reich, 2002;

Agren and Franklin, 2003).

Table 4.28: Interaction effect between soil amendments and different compaction levels on root: shoot ratio of maize and soybean

Amendment x bulk density($Mg\ m^{-3}$)	Maize	Soybean
Control x1.3	0.25	0.11
Control x 1.5	0.28	0.08
Control x 1.7	0.33	0.54
NPK Fertilizer x 1.3	0.79	0.16
NPK Fertilizer x 1.5	0.48	0.17

NPK Fertilizer x 1.7	0.41	0.25
PM x 1.3	0.80	0.18
PM x 1.5	0.35	0.13
PM x 1.7	0.37	0.36
½ PM + ½ NPK x 1.3	0.50	0.15
½ PM + ½ NPK x 1.5	0.34	0.16
½ PM + ½ NPK x 1.7	0.47	0.16
Lsd (5 %)	0.08	0.19

4.4 The impact of soil compaction and soil amendments and their interactions on nutrient uptake

Mineral nutrients are essential for plant growth and development. Increases in crop yield have therefore been associated with the provision of adequate amounts of nutrients through the application of mineral and organic fertilizers. The ability of plants to obtain nutrients from the soil is essentially related to their ability to develop extensive roots systems (Chen and Weil, 2011). The uptake of nutrients by plants is influenced by several factors including the root biomass and density prevailing conditions in soil-root environment such as compaction, porosity, aeration, moisture; inherent soil fertility; and application of mineral and organic fertilizers. Any factor that affects root growth and development therefore influences the magnitude of nutrient uptake. In this study, the impact of soil compaction and soil amendments on the uptake of N, P and K in maize and soybean were assessed.

The results (Table 4.29 and 4.30) showed that uptake of N, P and K by maize and soybean decreased with increasing bulk density in the order of 1.3> 1.5> 1.7 Mg m^{-3}. Uptake of the N, P and K at the 1.3 Mg m^{-3} was significantly ($P< 0.05$) greater than that of either 1.5 or 1.7 Mg m^{-3} under both maize and soybean. Nutrient uptake in maize ranged from 0.84 to 2.44 g/plant for N; 0.87 to 2.50 g/plant for P; and 0.47 to 2.46 g/plant for K (Table 4.29). The percentage reduction of NPK relative to 1.3 Mg m^{-3} was 50, 51 and 50 at 1.5 Mg m^{-3} and 66, 64 and 81 Mg m^{-3} at 1.7 Mg m^{-3}.

In soybean, nutrient uptake in g/plant for NPK ranged between 0.41 and 1.50, 0.46 and 1.57 and, 0.22 and 1.40 respectively with the lower and higher values for the 1.3 and 1.7 Mg m^{-3} (Table 4.30). Relative to 1.3 Mg m^{-3}, the percentage reduction in the uptake of N, P and K at the 1.5 Mg m^{-3} was 49, 50 and 49, respectively. The corresponding figures at the 1.7 Mg m^{-3} were 73, 71 and 84 %. The adverse soil conditions created by increasing soil compaction observed in this study could account for the recorded reduction in mineral uptake. These include high impedance to root growth, poor aeration due to decreased aeration porosity below the critical level of 10 % and potential poor soil-plant-water relationships. Reduction in N, P and K uptake with increasing soil compaction with its associated adverse soil conditions has been reported by several authors (Lowery and Schuler, 1991; Marschner, 1995; Raza *et al*., 2005).

Table 4.29: Impact of different soil compaction levels on maize nutrients uptake

Bulk Density (mg m^{-3})	**Nitrogen Uptake (g/plant)**	**Phosphorus Uptake (g/plant)**	**potassium uptake (g/plant)**
1.3	2.44	2.50	2.46
1.5	1.21	1.22	1.23
1.7	0.84	0.87	0.47
Lsd (5 %)	0.43	0.44	0.70

Lsd (least significant difference)

Table 4.30: Impact of different compaction levels on nutrient uptake of soybean

Bulk Density (Mg m^{-3})	Nitrogen uptake (g/Plant)	Phosphorous Uptake (g/Plant)	Potassium Uptake (g/Plant)
1.3	1.50	1.57	1.40
1.5	0.76	0.78	0.71
1.7	0.41	0.46	0.22
Lsd (5 %)	0.25	0.25	0.34

Lsd (least significant difference)

The stimulation of root growth, evidenced by the increases in root biomass recorded in this study coupled with the availability of nutrients increased the uptake of N, P and K over that of the Control treatment. This is indicated by the enhanced nutrient uptake by all the soil amendments applied (Tables 4.31 and 4.32). In maize, N uptake was in decreasing order of NPK> ½ PM + ½ NPK> PM> Control with a range of 1.08 to 2.03 g/plant (Table 4.31). The difference between PM and Control was not significant. Uptake of N was significantly greater ($p < 0.05$) in NPK and ½ PM + ½ NPK than all the other amendments (Table 4.31). The uptake of P varied between

0.66 and 3.44 g/plant with a decreasing order of NPK > ½ PM+ ½ NPK> PM> Control (Table 4.31). The significance in the difference in P uptake was similar to that of N. In the case of K, the trend in uptake was Control> ½ PM + NPK> NPK> PM with a range of 0.41 to 2.13 g/plant (Table 31). The differences in the uptake under Control and ½ PM + NPK and between NPK and ½ PM + ½ NPK were not

significant ($P > 0.05$) (Table 4.31). All other differences were significant. The application of NPK fertilizer enhanced N and P uptake by maize more than the other amendments possibly because these were readily available for uptake by greater root biomass produced under NPK. The combined mineral fertilizer and poultry manure also significantly ($P < 0.05$) increased NPK uptake by maize more than the sole application of PM. Similar observation was made by Hakansson and Lipeic (2000). The PM and the ½ PM + ½ NPK also increased the uptake of P over the Control as similarly reported by Onwonga *et al*. (2013).

In the case of soybean (Table 4.32), NPK uptake ranged between 0.48 and 1.29, 0.29 and 2.16, and 0.28 and 1.12 g/plant respectively. The trend in the magnitude of uptake however differed with the soil amendments for both N and P and, uptake was in a decreasing order of NPK> ½ PM + NPK> PM> Control. For the K, the trend was ½ PM + ½ NPK> Control> NPK> PM. The NPK and ½ PM + ½ NPK recorded higher ($P< 0.05$) N and P uptake than the Control and PM (Table 4.32). With the exception of PM uptake, no significant difference ($P> 0.05$) was recorded between the control and all the remaining amendments for K (Table 4.32). As observed under maize, and for the same assigned reasons, a more enhanced uptake of N and P was observed under NPK. Whilst ½ PM + ½ NPK improved NPK uptake over that of the Control.

Table 4.31: Impact of soil amendments on nutrients uptake of maize

Amendments	Nitrogen uptake (g/plant)	Phosphorous uptake (g/plant)	Potassium uptake (g/plant)
Control	1.12	0.66	2.13
NPK Fertilizer	2.03	3.44	1.24
Poultry manure	1.08	0.72	0.41
½ NPK * ½ PM	1.76	1.30	1.78
Lsd (5 %)	0.50	0.51	1.39

Lsd (least significant difference)

Table 4.32: Impact of soil amendments on nutrient uptake of soybean

Amendments	Nitrogen uptake (g/plant)	Phosphorous uptake (g/plant)	Potassium uptake (g/plant)

Control	0.48	0.29	0.93
NPK Fertilizer	1.29	2.16	0.78
Poultry manure	0.69	0.49	0.28
½ NPK * ½ PM	1.10	0.82	1.12
Lsd (5 %)	0.29	0.29	0.40

Lsd (least significant difference)

The ameliorative impact of soil amendment in reducing the adverse effect of soil compaction in nutrient uptake is depicted by the soil compaction x amendment interaction. In maize, this was more evident with the soil amendments that incorporated N, P and K, being the ½ PM + ½ NPK and the NPK fertilizer and for N and P uptake (Table 4.33). The impact of PM was not consistent. In the case of K, the application of soil amendments tended to depress the uptake by maize at each level of soil compaction (Table 4.33). In soybean (Table 4.34), the increase in N and P uptake at each level of soil compaction was consistent with all the soil amendments. The tendency for the depressed uptake of K was also evident (Table 4.34).

Table 4.33: Interactive effect of amendments and soil compaction on nutrient uptake of maize

Amendments * Bulk Density (M cm^{-3})	Nitrogen uptake (g/Plant)	Phosphorous Uptake (g/Plant)	Potassium Uptake (g/Plant)
Control X 1.3	1.79	1.31	3.74
Control X 1.5	1.10	0.53	2.12
control X 1.7	0.48	0.13	0.53
NPK Fertilizer X 1.3	3.66	5.21	1.91
NPK Fertilizer X 1.5	1.45	2.70	0.99
NPK Fertilizer X 1.7	0.97	2.42	0.81
PM x 1.3	1.32	1.21	0.69
PM x 1.5	1.05	0.72	0.41
PM x 1.7	0.88	0.23	0.13
½ PM + ½ NPK X 1.3	2.98	2.27	3.52

½ PM + ½ NPK X 1.5	1.27	0.91	1.41
½ PM + ½ NPK x 1.7	1.02	0.71	0.42
Lsd (5 %)	0.86	0.89	1.39

Table 4.34: Interactive effect of soil amendments and soil compaction levels on nutrient uptake of soybean

Amendments (g/Plant) * bulk density (Mg m^{-3})	**Nitrogen Uptake (g/Plant)**	**Phosphorus Uptake (g/Plant)**	**Potassium Uptake (G/Plant)**
Control X 1.3	0.80	0.59	1.66
Control X 1.5	0.50	0.25	0.98
Control X 1.7	0.13	0.04	0.14
NPK Fertilizer X 1.3	2.41	3.43	1.26
NPK Fertilizer X 1.5	0.94	1.76	0.64
NPK Fertilizer X 1.7	0.52	1.30	0.44
PM x 1.3	0.92	0.84	0.48
PM x 1.5	0.78	0.53	0.30
PM x 1.7	0.36	0.10	0.05
½ PM + ½ NPK Fertilizer X 1.3	1.87	1.43	2.21
½ PM + ½ NPK Fertilizer X 1.5	0.82	0.59	0.92
½ PM + ½ NPK fertilizer x 1.7	0.62	0.43	0.23
Lsd (5 %)	0.50	0.50	0.69

4.5 Relationship between Soil Compaction and Plant Parameters

The data on plant parameters were examined for correlations with bulk density and porosity using regression analysis. This was to ascertain the direction of change (positive or negative) in the measured parameters as bulk density or total porosity increases. The regression equations will facilitate the acquisition of relevant information regarding the response of the measured parameters of maize and soybean to a unit change in bulk density and porosity. The magnitude of the coefficient of determination (R^2) also provides the proportion of the variance in the measured parameters due to bulk density and porosity.

The relationship between bulk density and the plant parameters are presented in Figure 4.1 to 4.5. The results depicted the negative impact of increasing soil compaction on shoot biomass, effective root biomass, root penetration ratio and the root: shoot ratio of maize and soybean. In soybean, the root: shoot ratio increased with bulk density. The correlation coefficient (r) for maize were: -1.0, -0.93, -0.80 and 0.72 for shoot biomass, effective root biomass, root: shoot ratio and the corresponding R^2 values were: 1.0, 0.86, 0.64 and 0.52. Increasing soil compaction therefore decreases the magnitude of these measured parameters. The R^2 values imply that the bulk density accounted for 52 to 100 % of the variations in the magnitude of the measured parameters. The negative r for root: shoot ratio indicates that root biomass is depressed more than shoot biomass as soil compaction increases. An examination of the data revealed that root: shoot ratio of maize decreased as bulk density increased from 1.3 to 1.5 Mg m^{-3} and increased from 1.5 to 1.7 Mg m^{-3}. However, the magnitude of the increase could not offset that of the decrease, resulting in a general trend of decreasing root: shoot ratio.

The correlation coefficients (r) for soybean were: -0.98, -0.62, 0.83 and -0.95. The corresponding R^2 were: 0.96, 0.38, 0.69 and 0.91. All the measured parameters except root: shoot ratio, decreased in magnitude with increasing soil compaction. Bulk density accounted for 62 to 98 % of the variance in the measured parameters. The positive correlation between bulk density and root: shoot ratio accords with the generally observed trend of the shoot being more depressed than the root with increasing soil compaction as explained in section 4.3.6. This is the general response of the plants to stress, such as soil compaction, drought, moisture stress and nutrient deficiency (Marschner, 1995).

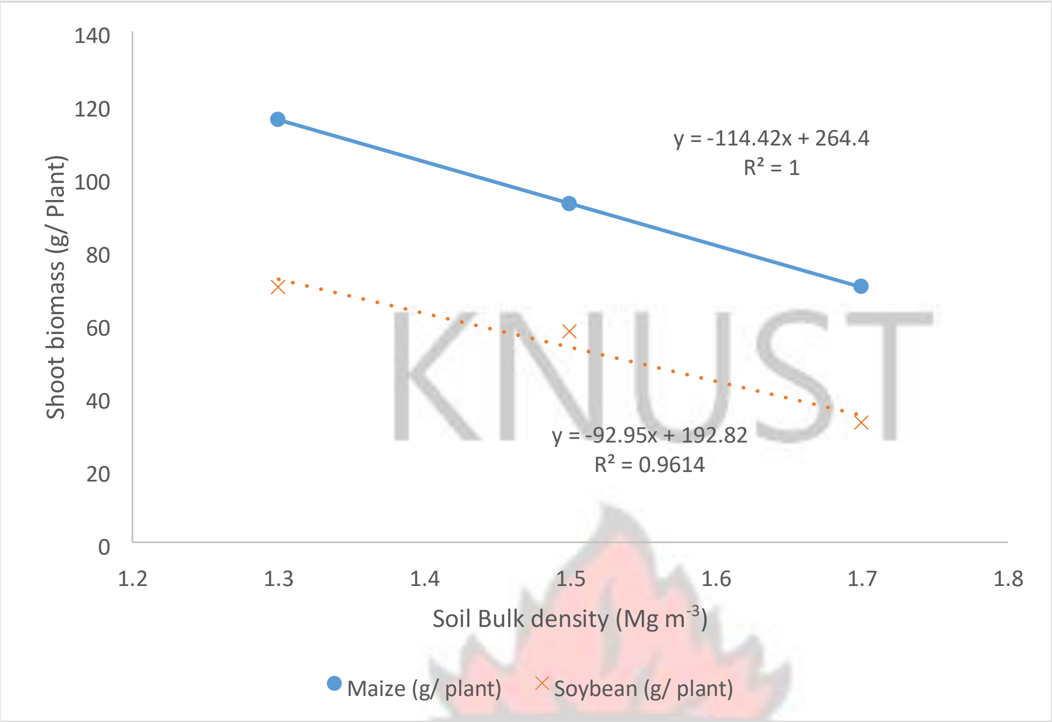

Figure 4.1: Relationships between bulk density and shoot biomass yield of maize and soybean

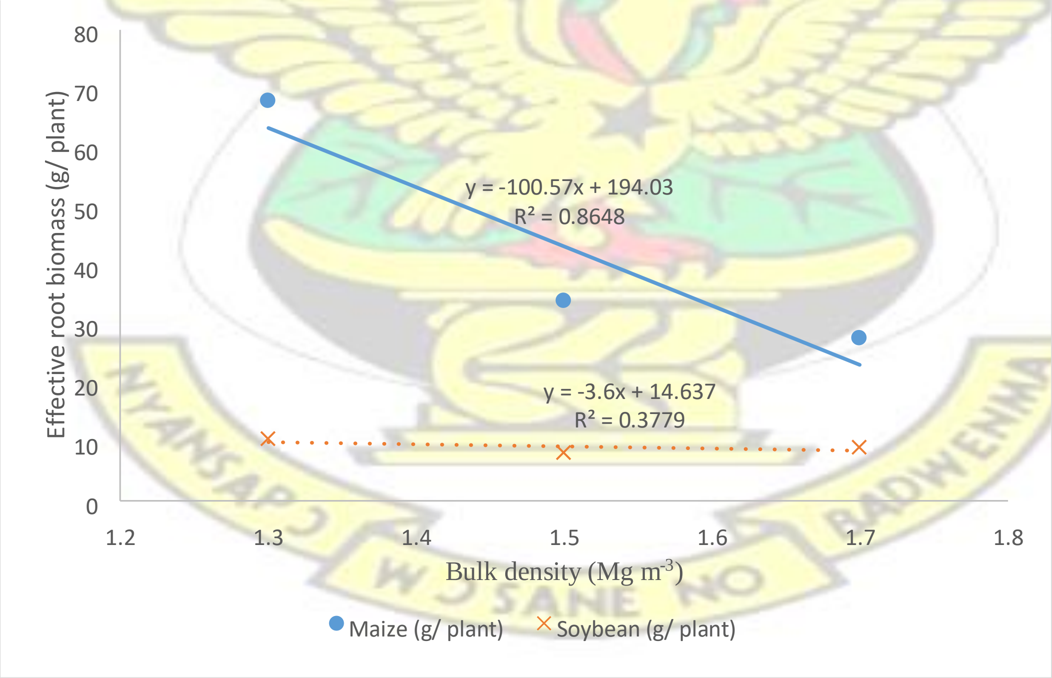

Figure 4.2: Relationships between bulk density and effective root biomass of maize and soybean

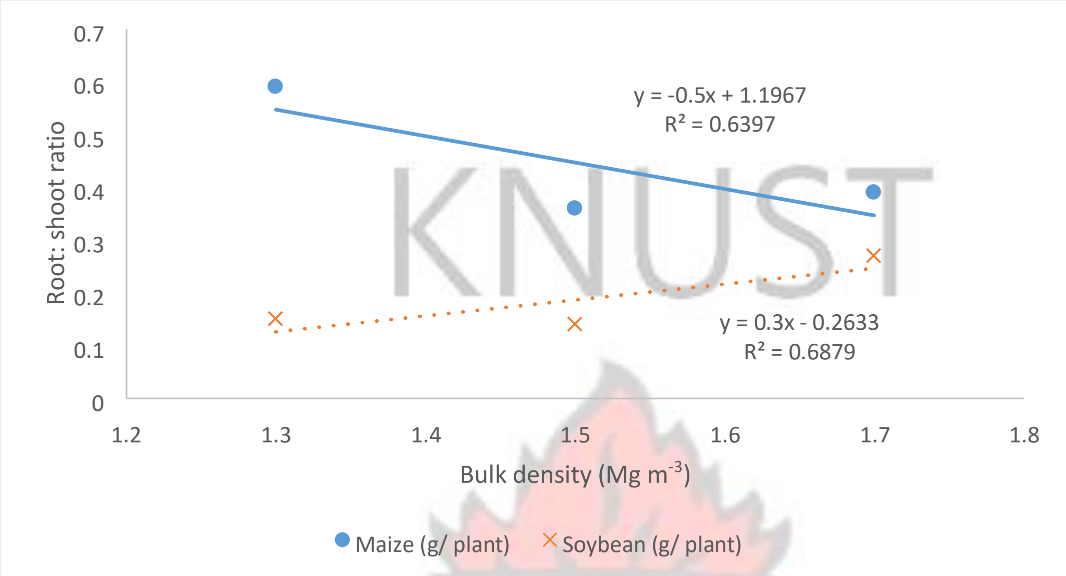

Figure 4:3. Relationships between bulk density and root: shoot ratio of maize and soybean

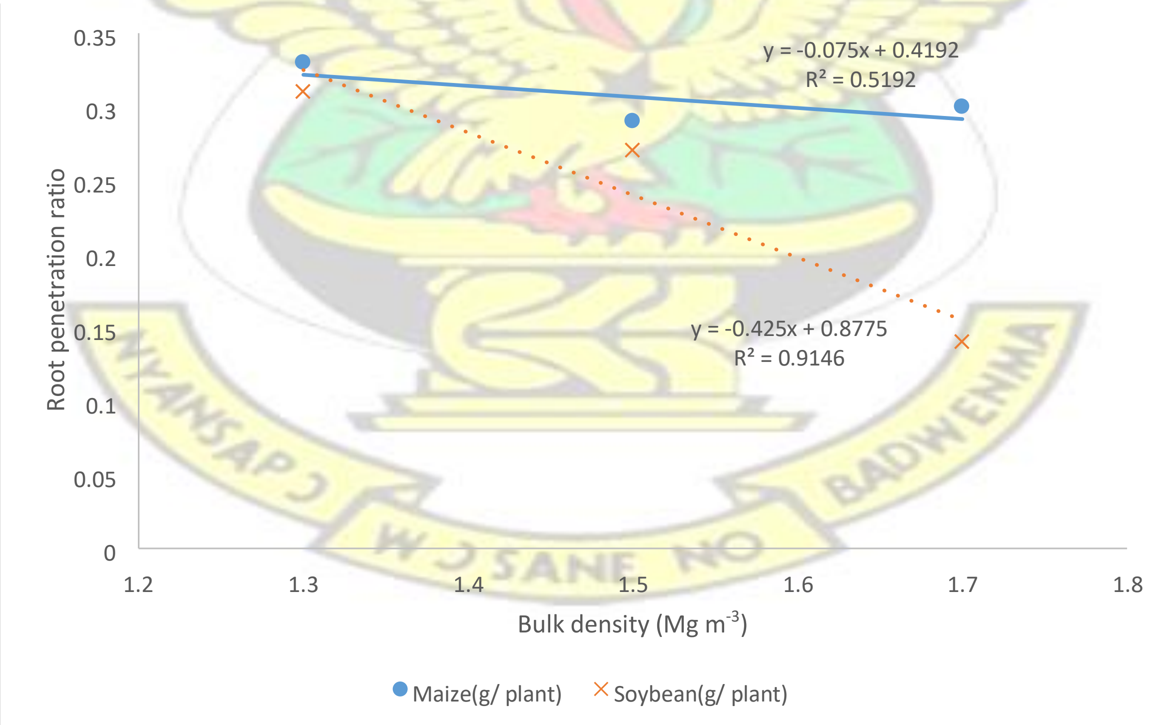

Figure 4.4: Relationships between bulk density and root penetration ratio of maize and soybean

The results of the relationships of soil total porosity with the measured plant parameters are presented in Figure 4.5 to 4.8. Total porosity correlated positively with all the measured parameters. The implication is that increasing porosity enhances the magnitude of shoot and effective root biomass, root penetration ratio and root: shoot ratio. The r values for maize were: 0.98, 0.98, 0.90 and 0.88 for shoot biomass, root biomass, root; shoot ratio and root penetration ratio respectively. The corresponding values for R^2 were: 0.86, 0.97, 0.81 and 0.78. Porosity accounted for 78 to 97 % of the variations in the measured parameters. In the case of soybean, the r values were: 0.93, 0.75, 0.71 and 0.84 for shoot biomass, effective root biomass, root: shoot ratio and root penetration ratio, respectively. The corresponding R^2 were: 0.86, 0.57, 0.50 and 0.70. Total porosity explained 50-86 % of the variations in the measured parameters.

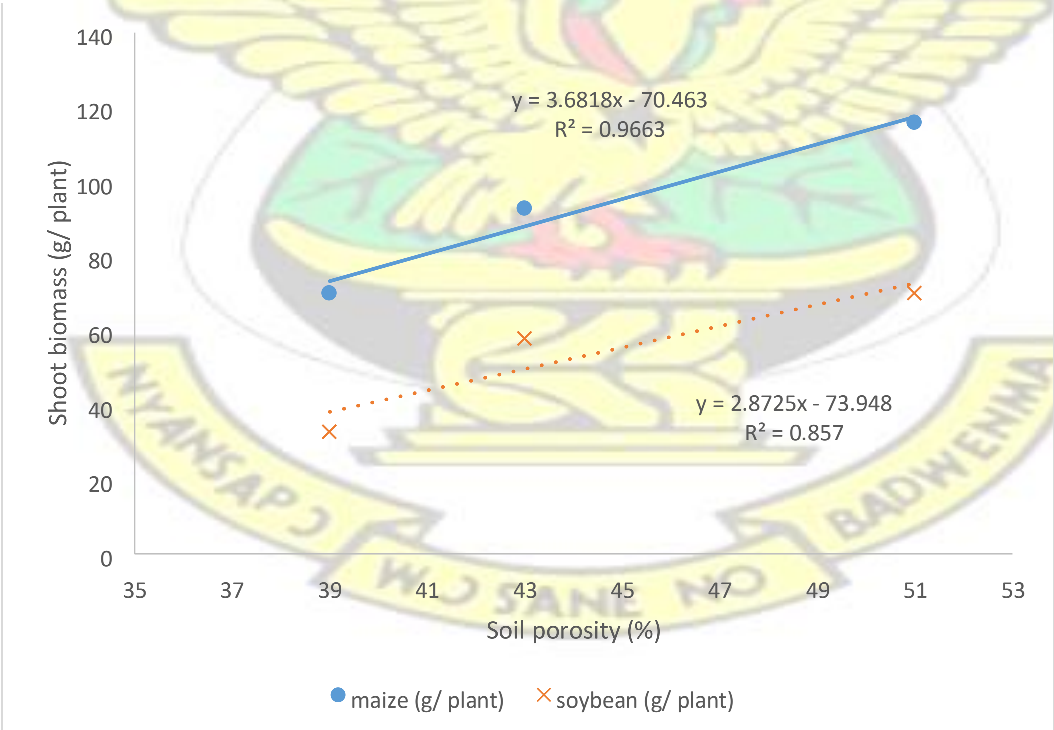

Figure 4.5: Relationships between soil porosity and shoot biomass yield of maize and soybean

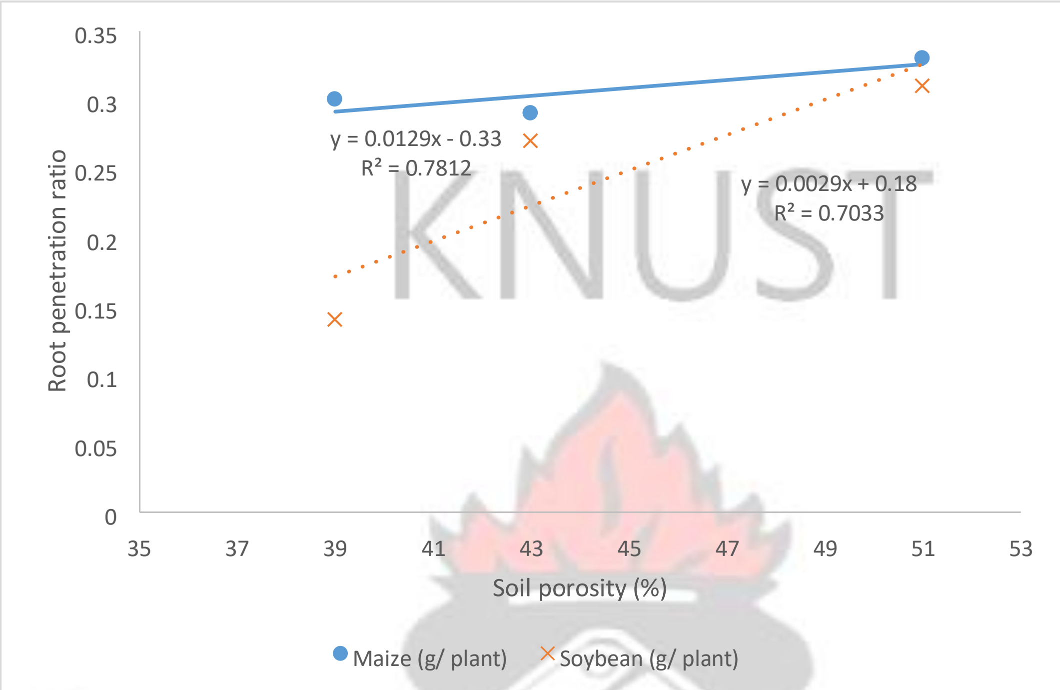

Figure 4.6: Relationships between soil porosity and root penetration ratio of maize and soybean

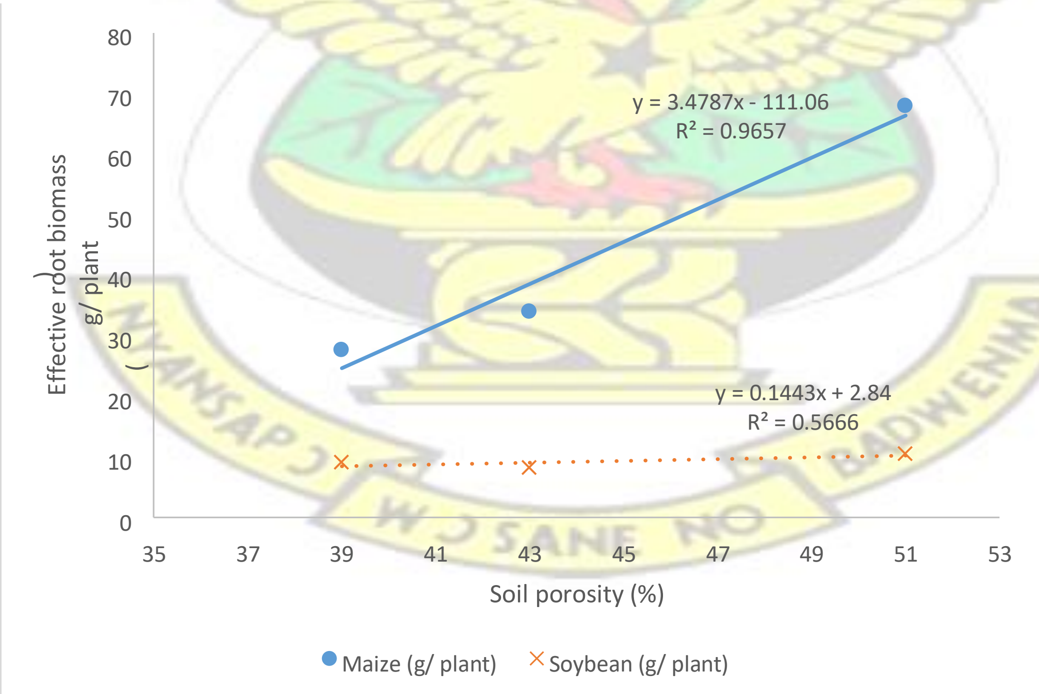

Figure 4.7: Relationships between soil porosity and effective root biomass of maize and soybean

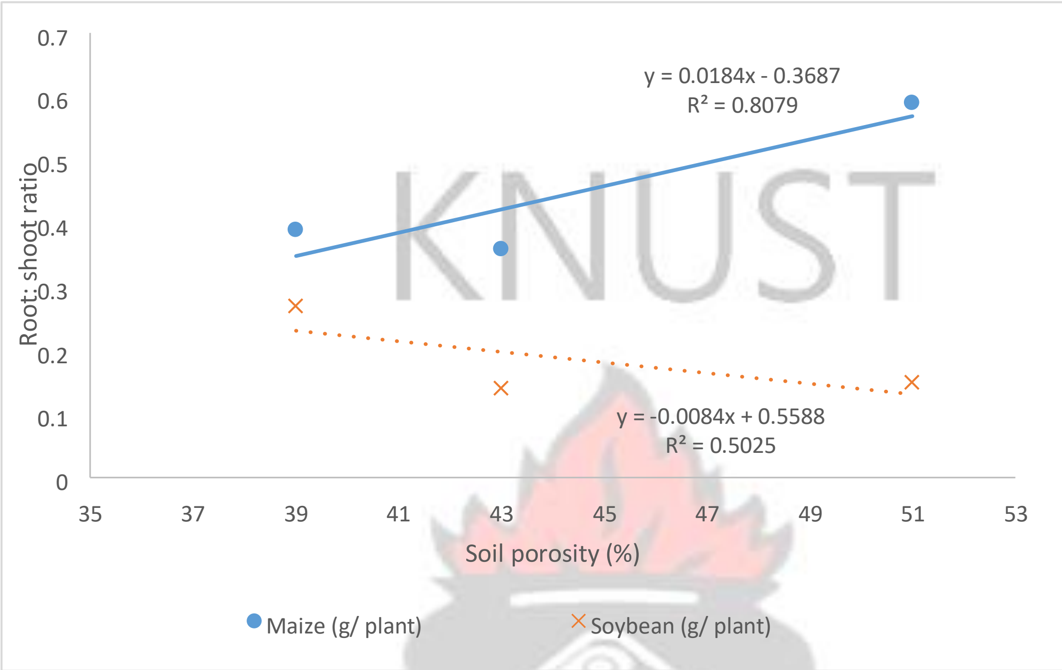

Figure 4.8: Relationships between soil porosity and root: shoot ratio of maize and soybean

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study has clearly shown the impact of different levels of soil compaction, amendments and their interactions on some soil physical properties and the growth and yield of maize and soybean. At a bulk density of 1.7 Mg m^{-3}, aeration porosity was reduced below the critical level of 10 % for favourable gaseous exchange.

Soil compaction further reduced crop growth, shoot and root biomass and root penetration ratio of maize and soybean. The magnitude of reduction increased as bulk density increased. The main effects of soil amendments manifested in the enhancement of the growth of maize and soybean over that of the control. Soil amendments enhanced plant height at each level of soil compaction. A similar impact was observed in root and shoot biomass yield and root penetration ratio of both crops.

Increasing soil compaction resulted in the accumulation of most of the root biomass in the uncompacted soil above the compacted layer. The addition of soil amendments increased the relative root biomass of maize in the uncompacted soil while that in the compacted soil where reduced. In the case of soybean, although the relative root biomass accumulated in the uncompacted soil was relatively greater than that of maize, the application of soil amendments tended to slightly decrease the relative root biomass over that of the Control.

High soil compaction induced more root growth in the uncompacted soil and the periphery of the soil core than the compacted zone. The peripheral relative root biomass was greater in soybean than in maize according to the trend, 1.7< 1.3< 1.5 Mg m^{-3}. Application of soil amendments reduced the peripheral relative root biomass of both crops. In maize, the least peripheral relative root biomass was recorded by the ½ PM × ½ NPK while the sole NPK amendment recorded the least peripheral relative root distribution in soybean.

The root penetration ratio (RPR) of soybean and maize decreased with increasing bulk density. The study showed that the impact of soil compaction on root proliferation was more severe on soybean than on maize. The applied soil amendments significantly increased the RPR of both crops in relation to the Control.

The shoot biomass of both crops decreased with increasing soil bulk density. The soil amendments significantly increased the shoot biomass of maize and soybean over the Control. The magnitude response of the crops to the soil amendments was greater in soybean than in maize.

Soil compaction and amendments significantly influenced root: shoot ratio of both crops. At the bulk density 1.3 to 1.5 Mg m^{-3}, the root: shoot ratio decreased with increasing compaction. Beyond the bulk density of 1.5 to 1.7 Mg m^{-3}, the root: shoot ratio increased with increasing soil compaction. The magnitude of the increase (1.5 to 1.7 Mg m^{-3}) could not offset that of the decrease (1.3 to 1.5 Mg m^{-3}), resulting in a general trend of decreasing root: shoot ratio. The soil amendments increased the biomass of both root and shoot but more so in the former than the later.

The uptake of N, P and K by maize and soybean decreased with increasing bulk density in the order of 1.3> 1.5> 1.7 Mg m^{-3}. Apart from the potassium, application of the soil amendments increased the nutrient uptake of the crops. The application of the NPK fertilizer enhanced more N and P uptake of maize and soybean than the other amendments due to the fact that they were readily available for uptake by the greater root biomass produced.

Soil compaction accounted for 52 to 100 % of the variations in the magnitude of the measured parameters of maize while 62 to 98 % were for soybean. Total porosity correlated positively with all the measured parameters except the root shoot ratio of soybean. Soil porosity accounted for 78 to 97 % of the variation in the measured parameters and 50 to 86 % to variations observed in soybean.

5.2 Recommendations

Soil compaction beyond 1.5 Mgm^{-3}, adversely affected root and shoot biomass yield of maize and soybean. Thus, the ideal bulk density for shoot biomass production of both crops should be 1.3 Mg m^{-3} or with a range of 1.3 to < 1.5 Mg m^{-3}.

The need for mineral fertilizer in enhancing crop growth on compacted soils and, soils low in nitrogen and soil organic matter has been demonstrated in this study, even in the case of soybean contrary to the general notion that nitrogen-fixing legumes do not need fertilizers, especially, N. Soil amendments, especially, NPK fertilizer should therefore be applied to enhance crop growth and development on scompacted soils. Soil testing should be done to know the right amount of fertilizers to apply.

Further studies should be conducted to simulate the growth parameters measured in the buckets to conditions on the field and the parameters correlated to yield.

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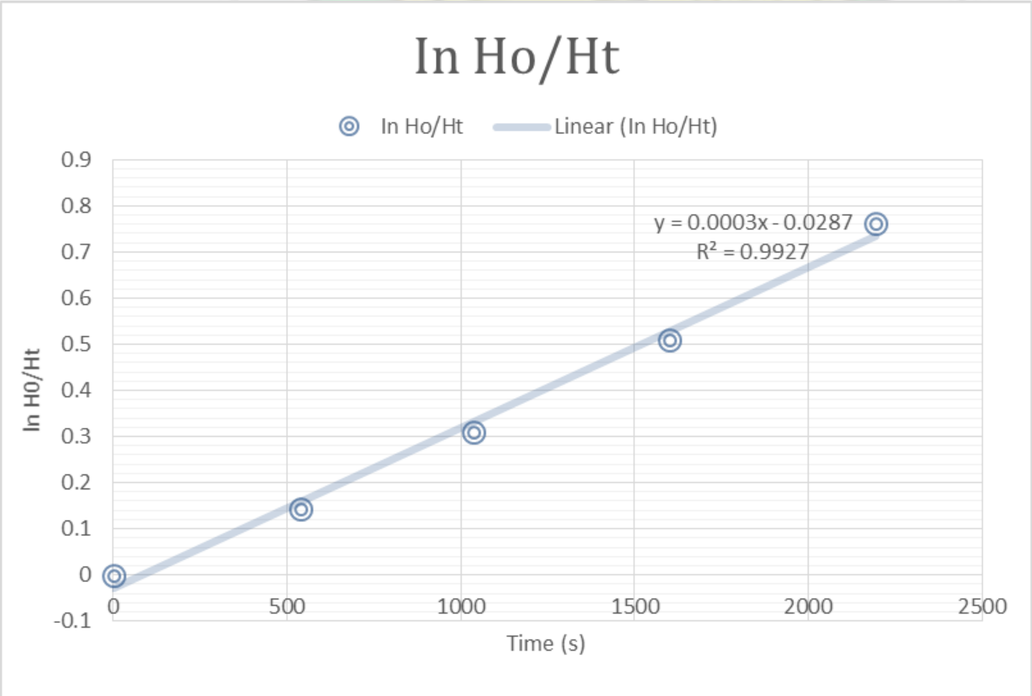
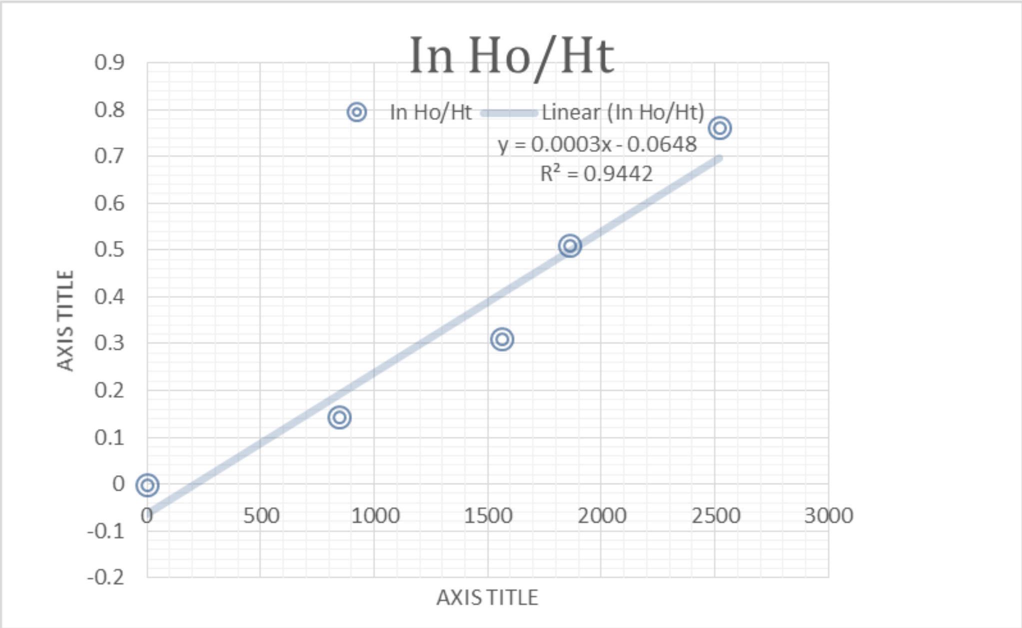
APPENDIX

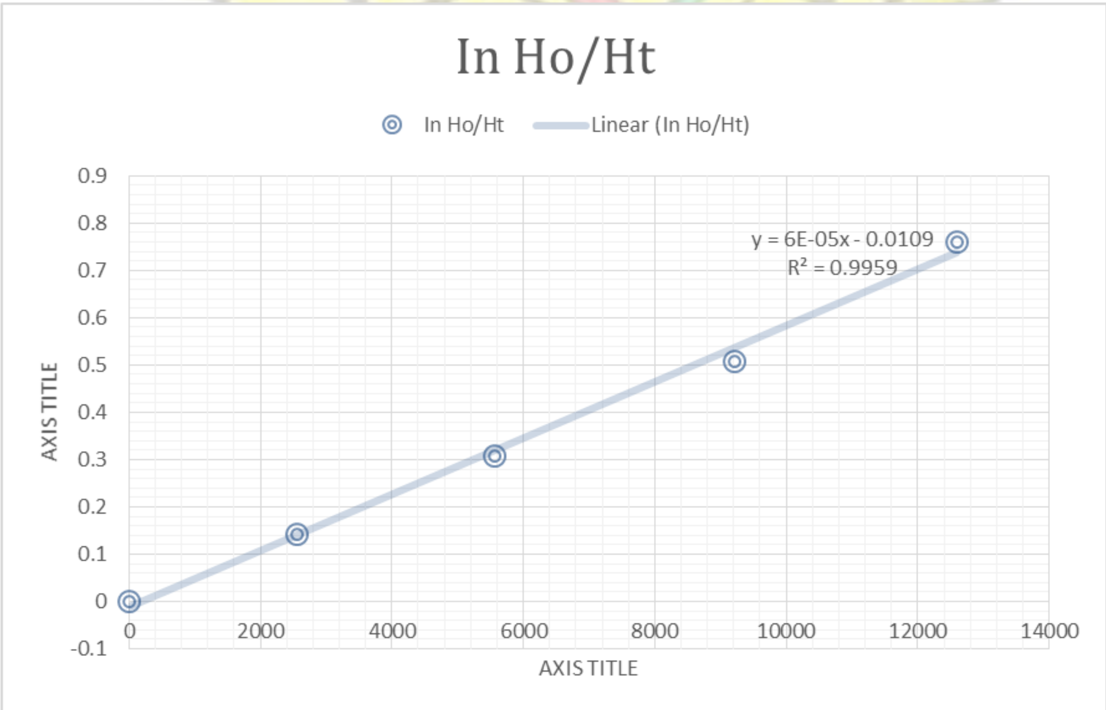


In Ho/Ht
In Ho/Ht
Linear (In Ho/Ht)
y = 0.0003x - 0.0287
R² = 0.9927
In H0/Ht
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
500
1000
1500
2000
2500
Time (s)

Appendix 1: Graph showing the coefficient of determination of saturated hydraulic conductivity for soil bulk density of 1.3 Mg m^{-3}.



Appendix 2: Graph showing the coefficient of determination of saturated hydraulic conductivity for soil bulk density of 1.5 Mg m^{-3}.



Appendix 3: Graph showing the coefficient of determination of saturated hydraulic conductivity for soil bulk density of 1.7 Mg m^{-3}.