SOIL MINERAL NITROGEN VARIATIONS AND NITROGEN UPTAKE OF MAIZE IN AN AMENDED COMPACTED SOIL

BY

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OCTOBER, 2014

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

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A Thesis submitted to The Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in partial fulfillment of the requirements for the award of the Degree of

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IN

SOIL SCIENCE

BY

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B.Sc. AGRICULTURE TECHNOLOGY (AGRONOMY OPTION) - UDS

OCTOBER, 2014

DECLARATION

I hereby declare that this submission is my own work towards the MPhil Degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree, except where due acknowledgement has been made in the text.

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ABSTRACT

Soil compaction is a major problem affecting soil quality in contemporary crop production due to mechanized operations on crop fields. The ameliorative/ compensatory effect of soil amendment on soil compaction has been reported in literature. However, the impact of soil amendment on mineral N dynamics and uptake by crops in compacted soils is yet to receive the needed research attention especially in Ghana. To bridge this gap in knowledge, field and pot experiments were respectively conducted at the Agricultural Research Station, Anwomaso, KNUST and the Mechanization Section of Agricultural Engineering Department, KNUST to study NH_4^+ and NO_3^- dynamics and crop uptake in compacted soils amended with poultry manure. Soils were compacted to three levels of soil bulk densities (1.3, 1.5, and 1.7 Mg m^{-3}) in the field experiment whilst that of the pot experiment was compacted to four bulk density levels (1.3, 1.5, 1.7 and 1.9 Mg m^{-3}). The compacted soils in both experiments were amended with two levels of poultry manure at 4 and 6 t ha^{-1} with a control (0 t ha^{-1}). The study was a factorial experimental laid out in randomized complete block design for field and completely randomized design in the pot experiment with three replications. Parameters measured were plant height, stover weight, crop N uptake, root length and biomass, microbial biomass carbon and nitrogen, ammonium and nitrate - nitrogen. The results revealed that soil compaction, poultry manure amendments and their interactions significantly influenced ($P < 0.05$) mineral N levels, N uptake and agronomic characteristics of maize. Mineral nitrogen (NO_3^- -N and NH_4^+ -N) generally increased from 21 to 42 days after amendment (DAA) and declined at 63 DAA in both experiments. Levels of NO_3^- -N (7.10 – 61.90 mg N kg^{-1} soil) were higher than that of NH_4^+ -N (5.69 – 36.78 mg N kg^{-1} soil) suggesting more losses of N from the system since N stored in the form of NO_3^- is subject to more leaching losses than NH_4^+. Soil compaction generally resulted in decreased NO_3^- -N and NH_4^+ -N levels, however, applications of poultry manure was associated with a significant ($P < 0.05$) increase in mineral N levels in both experiments. Generally, amendment and compaction interacted to significantly affect NO_3^- levels. The results obtained revealed that the main effect of soil compaction did not influence soil microbial biomass. However, the interactive effect of bulk density and amendment significantly ($P < 0.05$) influenced microbial biomass carbon and nitrogen contents of the soil such that the highest microbial carbon was recorded under 4 t ha^{-1} poultry manure in soil bulk density of 1.3 Mg m^{-3} and the highest biomass N recorded in soils of bulk density of 1.3 Mg m^{-3} treated with 6 t ha^{-1} poultry manure. Application of 6 t ha^{-1} poultry manure significantly ($P < 0.05$) increased N uptake and grain yield of maize crop in both experiments. Maximum N uptake were observed when poultry manure was applied at the rate of 6 t ha^{-1} on soil of bulk density 1.3 Mg m^{-3}. The highest grain yields of 3004 kg ha^{-1} and 2453 kg ha^{-1} were respectively obtained in field and pot experiments. Plant height, stover yields, root length and biomass generally increased in amended plots over the control plots. However, increasing bulk density beyond 1.5 Mg m^{-3} significantly decreased these parameters.

DEDICATION

I dedicate this work to my parents Mr. and Mrs. Agbeshie for their support throughout my period of study.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
Bd	Bulk Density
CRD	Completely Randomized Design
CRI	Crop Research Institute
DAA	Days after Amendment
ECEC	Effective Cation Exchange Capacity
EDTA	Ethylenediamenetetraacetic Acid
FE	Fumigation and Extraction
HSW	Hundred Seed Weight
KNUST	Kwame Nkrumah University of Science and Technology
MB	Microbial Biomass
MBC	Microbial Biomass Carbon
MBN	Microbial Biomass Nitrogen
NH_4^+ -N	Ammonium - Nitrogen
NO_3^- - N	Nitrate – Nitrogen
NRCS	Natural Resources Conservation Service
PM	Poultry Manure
R6	Physiological Maturity
RCBD	Randomized Complete Block Design
SRI	Soil Research Institute
SOM	Soil Organic Matter
UNPD	United Nations Population Division
USDA	United States Department of Agriculture
V12	Twelfth-leaf growth stage
WAP	Weeks after Planting

CHAPTER ONE

1.0 INTRODUCTION

Nitrogen (N) is key in plant nutrition because of its strong influence on crop yields (Havlin *et al*., 2005). It is an important component of amino acids, chlorophyll molecules and enzymes which are essential for plant growth (Taiz and Zeiger, 2006). It is absorbed by plants as ammonium (NH_4^+) and nitrate (NO_3^-) in the soil following mineralization. Various sources of organic N constitute 90 % of the soil total N in mineral soils (Olk, 2008). It is however estimated that about 1- 4 % of organic N is mineralized (NH_4^+ and NO_3^-) for plant uptake (Tisdale *et al*., 1985).

Plant nutrient uptake is the process whereby roots take up nutrients from the soil solution and transport to the various aerial portions of the plant (Havlin *et al*., 2005; Nwachukwu and Ikeadigh, 2012). According to Allen and David (2007), nutrient uptake is mostly affected by soil management practices, environmental conditions, nutrient concentrations and their forms in the soil.

Soil compaction, a major biophysical constraint to the productivity of crop lands, is a significant factor influencing nutrient uptake and crop growth. Good soil physical properties are required for nutrient uptake by crops. According to Balesdent *et al*. (2000), agricultural soils must be resistant to varying levels of land degradation in order to attain the requirement of sustainability and input-saving crop cultivation technologies, to enhance food security. However, the traditional low-input agriculture practiced by many smallholder farmers, characterized by failure to replenish mineral nutrients especially N taken from the soil, is slowly reducing many of the soils to almost inert systems (Stoorvogel and Smaling, 1990).

Soil compaction is often characterized by increased soil bulk density, reduced permeability and decreased soil porosity which are all used as indicators in soil compaction studies (Holtz *et al*., 2010). According to Birkeland (1984), differences in bulk density is attributed to the relative proportion and gravity of solid organic and inorganic particles and to the porosity of the soil. Areas of compacted soil affects root growth and thus may reduce water and nutrient uptake of less soluble minerals (Grzesiak, 2009). Soil compaction may also lead to reduced aeration and water infiltration (Hamza and Anderson, 2003). The overall impact of soil compaction are increased erosion, decreased plant development and yield.

Maize (*Zea mays* L.) production is widespread among farmers in Ghana. The goal of many farmers in crop production is to achieve high crop yields which in many cases is constrained by low soil fertility and soil compaction, etc. compounded by erratic rainfall patterns.

Reports on the detrimental effects of soil compaction on soil properties, nutrient uptake, crop growth and yield have been documented by several scientists globally. The effects of soil compaction on N mineralization of organic materials have also been reported by Lipiec and Stepniewski (1995) and De Neve and Hofman (2000), among others. According to the authors, N mineralization in compacted soils is influenced by poor soil aeration, reduced water infiltration and nutrient losses. Studies on crop growth in compacted soils on the field where abiotic conditions cannot be controlled is difficult, costly and requires time (Ocloo, 2012). Therefore, experiments on soil compaction are normally conducted in the laboratory where such conditions are controlled. In Ghana, there is limited data on the compensatory effect of poultry manure amendment on soil compaction with regards to nutrient availability and uptake by crops. The relevance of such useful information cannot be overlooked in the era of increasing agricultural mechanization. The few works on soil compaction in the country by Ocloo (2012) and others were greenhouse based and only examined growth response to varying levels of soil bulk density, a proxy of soil compaction. This study was therefore conducted in both field and pot to examine the influence of poultry manure amendment on mineral nitrogen availability, uptake and growth of maize in compacted soils, lending credence to the fact that nitrogen is the most limiting nutrient to crop growth in the country.

Specifically, the study aimed to:

i. evaluate ammonium - nitrogen (NH_4^+ - N) and nitrate - nitrogen (NO_3^- - N) levels in compacted soils under poultry manure amendment.
ii. determine N uptake by maize in response to poultry manure amendment as affected by soil bulk density.
iii. investigate the impact of poultry manure application on crop growth and yield in compacted soil under both field and pot experiments.

It was hypothesized that soil mineral nitrogen and nitrogen uptake of maize will vary considerably under different levels of soil compaction and organic soil amendments.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 What is soil compaction?

The Soil Science Society of America (2008) defined soil compaction as the process by which soil particles become closely packed to each other to reduce pore space causing an increase in the soil bulk density. Kuht and Reintam (2004) also defined soil compaction as the increase in the soil bulk density which alters the physical properties of the soil.

Compacted soils can be caused by traffic of animals and humans. Soil compaction has been regarded as a serious problem confronting mechanized farming and may adversely impact on several soil processes and properties and the final crop yield (Shafiq *et al*., 1994; Ramazan *et al*., 2012). In compacted soils, the frequently used indicators include soil bulk density and/or soil strength (Bennie, 1990; Kozlowski, 1999; USDA-NRCS, 1999).

2.1.1 Impact of agricultural mechanization on soil compaction

In the last two centuries, the population of mankind has increased drastically from 0.85 billion to over 7 billion (UNPD, 2013). To meet the food requirements of the ever increasing population, mechanization of operations in agriculture has evolved to increase the output of the total yield per hectare of crops. The use of heavy machinery in mechanized agriculture is an important aspect in modern farming activities with its associated benefits (Ramazan *et al*., 2012). However, its usage will require good management practices to avoid soil related problems affecting plant growth (Raghavan *et al*., 1990).

Pressure from agricultural machinery, animal trampling and human trafficking increases soil compaction with its associated increased soil bulk density, reduced aeration and increased soil strength (Aliev, 2001; Ohtomo and Tan, 2001; Hamza and Anderson, 2003). The intensive and long - term use of agricultural machinery increases soil compaction. Increased soil compaction caused by heavy machinery adversely affects important physical properties of the soil including nutrient flow and hydraulic conductivity (Radford *et al*., 2000; Hamza and Anderson, 2005; Singh and Malhi, 2006). The effects of soil compaction on soil physical properties alter all biological and several soil chemical processes including oxidation processes, ion exchange processes, etc. (Kuht and Reintam, 2004).

Irrespective of the process leading to soil compaction, its net effect is reflected in the reduction in air porosity (Grable, 1971), of which greater significance is attached to changes in pore size distribution especially the macropores. Porosity as defined by Harris (1971) is the fraction of pore space volume to that of the total volume of the soil. Macropores are associated with sufficient soil air and faster movement of water and particles through the soil and this describes the volumetric proportion of pores in the soil larger than 30 µm diameter (Mclaren and Cameron, 1996).

According to Omi (1986), the impact of soil compaction on drainage or infiltration rate can be attributed to the compactive force which affects soil structure. Significant relationships have been found among increasing bulk density, decreasing infiltration, and decreasing porosity (Raza, *et al*., 2005). Alterations in soil basic properties (bulk density and porosity) influences the water retention and hydraulic conductivity which adversely affects infiltrability and plant available water storage capacity (Zhang *et al*., 2005). Poor water infiltration in compacted soils could lead to surface runoff; causing waterlogging and aeration problems (Gifford *et al*., 1977). Pagliai *et al.* (2003)

reported that excessive use of heavy agricultural machinery decreased soil porosity which correlated with a decreased hydraulic conductivity and increased soil penetration resistance.

Decline in agronomic yields as influenced by soil compaction due to mechanized agriculture has been reported in crop production (Duiker, 2004; Sadras *et al*., 2005). Stunted plant growth in compacted soil exhibits the negative effects of increased soil bulk density. Retarded growth, small grain heads and yield, shallow rooting system and decreased nutrient contents of the plant are manifestations of soil compaction (Ramazan *et al*., 2012).

2.1.2 Soil fertility and crop nutrient uptake in compacted soils

Mitchell *et al*. (2000) defined fertility of a soil as the ability of that soil to provide nutrients which can sustain plant development and conserve environmental quality. Adequate nutrition is achieved when plants possess a better rooting system which delivers sufficient water and nutrients for its growth (Bengough *et al*., 2006; Chen and Weil, 2011). According to Chen and Weil (2011), soil compaction may hamper extensive root growth and affect nutrient availability to plants. Limited access to nutrient and water are the major setbacks to proper development of crops and yield in compacted soils (Raza *et al*., 2005). It is documented that compacted soils have reduced pore spaces and this may limit the elongation of plant roots, leading to limited nutrient uptake (Li *et al*., 2002).

The work of Lipiec *et al*. (2003) on plant growth as affected by soil compaction indicated that, increasing bulk density resulted in a decreased nutrient uptake. Raza *et al*. (2005) reported that soil compaction negatively influenced uptake of soil nutrients and concluded that N uptake declined with increasing soil compaction. Chen and Weil

(2011) also attributed reduction in maize yield to reduced nutrient uptake caused by the adverse effect of compacted soil layers on root growth. This phenomenon is mainly ascribed to the mechanical impedance to root growth (Silva *et al*., 2011). However, application of organic fertilizers to soil can encourage nutrient uptake especially mineral N (Jones *et al*., 2007).

2.2 Impact of mineral fertilizers and organic amendments on soil properties

Application of fertilizers (mineral and organic) has been documented to positively impact yield of crops via influence on nitrogen status of the soil (Soumaré *et al*., 2003; Muñoz *et al*., 2008). According to Shah *et al*. (2010), chemical fertilizers provide nutrients for crop growth and improve yields but the use of mineral fertilizers comes at a high cost of purchase and as such its low usage in balanced proportion results in lower crop yield than the potential yield expected (Ahmad, 2000).

Continuous soil application of inorganic fertilizers under intensive commercial agriculture leads to soil degradation (Sharma and Mittra, 1991) as a result of organic matter loss and consequently leads to nutrient imbalance, low soil pH and consequently low yield (Ayoola and Makinde, 2007)

However, application of organic amendment significantly ameliorates soil properties and enhance productivity through the provision of nutrients and improvement of yields (Stone and Elioff, 1998). According to Nguyen (2010), application of manure does not only supply adequate amounts of nutrients in comparison with chemical fertilizer, but supply organic carbon to the soil which consequently enhance physical properties such as water infiltration and soil aeration. Also, the use of organic amendments in farming in recent years has been found to reduce N-losses (Dalgaard *et al*., 1998; Aronsson *et al*., 2007).

Poultry manure is considered to be of high importance in crop production compared to all other sources of manure produced by livestock (Omisore *et al*., 2009). It contains between 2.0 - 3.5 % N (Boateng *et al*., 1997). According to Boateng *et al*. (2006), poultry manure applications registered over 53 % increment in the N levels of the soil. Poultry manure also effectively decreased phosphorus content in runoffs and NH_3 volatilization as compared to inorganic fertilizers (Moore and Edwards, 2005). The application of poultry manure helps enhance soil fertility by improving the physico-chemical properties of the soil (Farhad *et al*., 2009). It supplies adequate organic carbon and significantly influenced soil physical properties (Hillel, 1998). Studies have also confirmed that application rates and types of poultry manure play a key role in enhancing soil properties (Gilley and Risse, 2000). Moore and Edwards (2005) concluded that poultry manure increased soil pH from 5.1 – 5.3 at the start to 5.8 – 6.5 during a long-term soil experiment treated with alum. In their studies, DeLaune *et al*. (2004) recorded improved soil fertility status after application of poultry manure.

2.3 Role of N in crop production

Maize crop needs nitrogen in the highest quantities relative to other nutrients (Luce *et al*., 2011) and is an important component of amino acids, enzymes, hormones and chlorophyll molecules (Taiz and Zeiger, 2006). It is very critical for the growth and development of plant and the uptake of other nutrients present in the soil (Tammeorg, 2010). Hassan *et al*. (2013) reported that N is insufficient in majority of farm lands for crop growth and the judicious application of N based fertilizers are used to subdue this deficiency.

The application of nitrogen enhance rapid growth and dark green colour of crops (Malival, 2001). Nitrogen application to increased leaf area index and grain yield per unit area (Okpara *et al*., 2007). A research conducted by Olaniyi *et al.* (2008) indicated that excess application of N based fertilizers significantly increased crop yields but disposed amaranthus to lodging.

Among all the soil nutrients, N exhibits the highest mobility, depletes easily and strongly leached when applied in excess (Olaleye *et al*., 2008). Zhang *et al*. (2009) reported that a greater part of N is lost to the environment through denitrification, leaching and NH_3 volatilization. This leads to environmental degradation via acidification of agricultural lands and eutrophication of water bodies (Reeves *et al*., 2002). On the other hand, Malavolta *et al*. (1997) observed that deficiency symptoms associated with N initially appears on the tips of matured corn leaves, as yellowing in an inverted V shape.

2.4 Effect of soil compaction on soil microbial biomass

The presence and activities of soil microbes in nutrient cycling has resulted in the increased study and determination of microbial biomass (MB) (Azam *et al*., 2003). Marinari *et al*. (2006) stated that soil MB constitutes the active part of soil organic matter, which is responsible for the breakdown of organic matter. Microbial biomass is responsible for nutrient mineralization and is a small but the most reactive source of major plant nutrients (C, N, P and S) (Jenkinson and Ladd, 1981; Dick, 1992).

Soil moisture, temperature, pH and agronomic practices such as fertilization affect microbial functions and populations (Blagodatskii *et al*., 2008). Magdoff and Weil (2004) stated that changes in microbial functions and population take place with application of fertilizer and tillage management. However, the effect of soil compaction associated with conventional tillage results in a decreased soil microbial biomass (Li *et al.*, 2003). Silva *et al*. (2011) found that altered soil pore size and distribution, lowered O_2 and CO_2 diffusion rates, increased population of anaerobic microsites and the resultant decline in microbial activity was associated with the adverse effects of soil compaction. Li *et al.* (2003) observed a significant decrease in soil MB and functions in compacted soils. The work of Silva *et al*. (2011) also recorded a decline in microbial activity which resulted in a decreased microbial biomass and attributed this to unfavourable growth of soil microbes under increased soil compaction. On the contrary, Entry *et al.* (1996) reported that compaction and tillage practices had no coherent impact on microbial biomass in a loamy sand soil.

2.5 N mineralization in compacted soils

Mineralization is the transformation of an element from its organic form to the mineral form by the action of micro-organisms (Gilmour, 2011). Plants absorb nitrogen in the form of ammonium and nitrate through the process of mineralization (Omisore, 2009). Nitrogen mineralization of organi fertilizers is very important in the availability of plant N (Pengthamkeerati *et al*., 2006). In organic manure, about 50 - 75 % of total N is in the organic form and needs to undergo mineralization (Figure 2.1) before it can be absorbed by plants (Havlin *et al*., 2005).

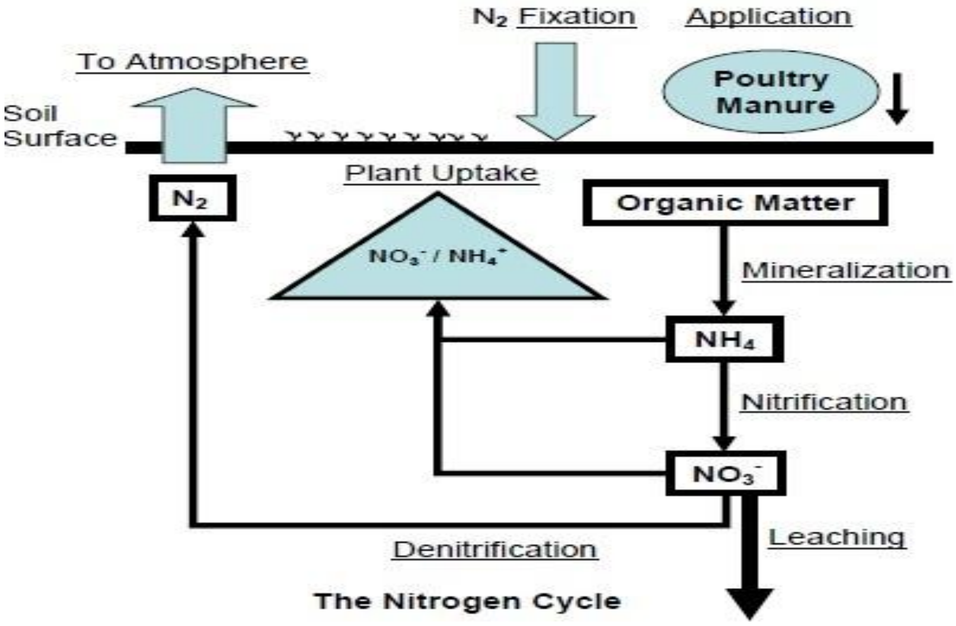


Figure 2.1: The Nitrogen Cycle (Myrold, 1999).

Therefore, knowledge of nitrogen mineralization is important when evaluating the effect of management practices and application of organic fertilizers on soil quality (Watts *et al*., 2007). Franzluebbers *et al*. (1994) observed that N mineralization is partially linked to the quality of organic matter in the soil and as such agronomic practices that build up organic matter will significantly improve N mineralization (Wood and Edwards, 1992; Torbert *et al*., 1999).

The main agents of mineralization is soil microbial biomass. It is the living portion of organic matter and responsible for biodegradation of organic matter and nutrients mineralization (Marinari *et al*., 2006). Soil microbial biomass is affected by soil environmental conditions including soil compaction (Shestak and Busse, 2005). Compacted soils with their associated high bulk densities, reduced infiltration and decreased soil macropore affect the environment of these soil living organisms (Li *et al*., 2003). Under reduced aeration and prolonged saturated conditions, N mineralization is reduced. Silva *et al*. (2011) reported that decrease in NO_3^- -N levels in compacted soils is influenced by anaerobic conditions caused by soil compaction that affect soil microbes. Pengthamkeerati *et al*. (2005) reported that decreased functions of microbes was associated with negative influence of soil compaction. Li *et al*. (2002) indicated that increasing bulk density from 1.0 to 1.6 Mg m^{-3} reduced actinomycetes, bacteria and fungi population of the soil which in turn reduced N mineralization.

2.6 Influence of soil compaction on plant growth and yield

The consequences of soil compaction is noted as a key component in mechanized farming which decreases crop yield (Domzal *et al*., 1987; Li *et al*., 2002). Glab (2007) reported that compacted soil layers due to mechanization of operation in farming can degrade soil quality and decrease crop yield. Crop yields will decrease when there is insufficient aeration, nutrient and water uptakes by plant roots due to soil compaction (Boone and Veen, 1994).

An efficient rooting system is one that delivers adequate nutrient and water for plant growth and anchorage in the soil (Bengough *et al*., 2006). Soil compaction decreases macropores which are responsible for rapid flow of water and solute in the soil profile (Mclaren and Cameron, 1996). The reduction in soil macropores result in the mechanical impedance of root elongation which consequently affect root growth. According to Rab (2004), soil macropore volume < 10% generally resulted in restricted root growth and development. Grzesiak (2009) reported that moderate and severe soil compaction levels resulted in reduction in shoot and root growth of maize.

Busscher and Bauer (2003) noticed decreased shoot, root growth and consequently reduced grain yields of plants as a result of mechanical impedance of roots in compacted soils. According to Canarache *et al.* (1984), a unit increase in soil bulk density resulted in a reduced maize grain yield of 18 % compared to the yields of non-compacted plots. Oussible *et al.* (1992) reported a decrease in grain and straw yields of wheat by 12 – 23 % and 4 - 20 % respectively when a clay loam soil was compacted from an initial bulk density of 1.33 to 1.52 Mg m^{-3}. Ishaq *et al.* (2001) also observed a similar trend. They observed a reduction in wheat biomass and yield between 38 - 39 % when soil was compacted to 1.93 from 1.65 Mg m^{-3} soil bulk density. Motavalli *et al*. (2003) reported that compacted clay pan soil decreased corn silage and grain yield during two cropping seasons. Sharanappa (2002) reported a significant increase in corn grains by 7.62 % after poultry manure was applied.

2.7 Summary of literature review

It has been documented that soil compaction is a major problem confronting mechanized agriculture and adversely affects soil fertility through increased bulk density, reduced aeration, decreased nutrient uptake, restricted root growth and consequently decline in crop yields. The literature reviewed indicated that soil compaction greatly affects N mineralization and N uptake. Although nutrients in inorganic fertilizers are rapidly absorbed by plants, application of organic amendments does not only improve crop yields but also improves soil physical properties. From the literature reviewed, there is a research gap in Ghana on the interactive effect of soil compaction and application of poultry manure amendment on mineral N variation and uptake during a cropping cycle and the implication for crop growth. Nitrogen uptake is influenced by fertilizer application and the ability of roots to move in deeper areas to pick up nutrients. In order to manage nutrient availability in compacted soils, there is the need to understand how soil compaction affect the nutrient release during decomposition and mineralization of organic amendments.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of experimental site

The experiment was carried out during the minor season of 2013 in the Semi – deciduous forest agro – ecological zone of Ghana. The study consisted of both field and pot experiments (green - house experiment). The field experiment was carried out at the Agriculture Research Station of the Kwame Nkrumah University of Science and Technology (KNUST), Anwomaso, whilst the pot experiment was conducted in a plant house at the Mechanization Section of Agriculture Engineering Department, KNUST, Kumasi.

Anwomaso is located in the Ashanti Region of Ghana and geographically located in latitude 06^{o} 43'N and longitude 1^{o} 36'W. It is characterized by a bimodal rainfall pattern with an annual rainfall amount of 1450 mm. The major rainy season starts from March - July whilst the minor season starts from September - November. The soil is described as Ferric Acrisol (Adu, 1992) and belongs to the Asuansi series with about 15 cm thick top layer of dark gritty sandy loam. The area of study has been under cultivation of arable crops (mainly maize in rotation with other crops) for the past 20 years. The soil in the area is generally low in fertility.

3.2 Field and pot experiments

3.2.1 Crop cultivar used

Omankwa maize variety was used as test crop. It is an early maturing (90 – 95 days), drought tolerant, quality protein maize with a yield potential of 5.0 t ha^{-1}. The seeds were obtained from the Crops Research Institute (CRI) at Fumesua near Kumasi.

3.2.2 Treatments and treatment combinations

The treatments consisted of soils with three (3) different compaction levels or bulk densities (ie 1.3 (Bd_1), 1.5 (Bd_2) and 1.7 (Bd_3) Mg m^{-3}) for the field experiment and soils with four (4) different compaction levels (1.3 (Bd_1), 1.5 (Bd_2), 1.7 (Bd_3) and 1.9 (Bd_4) Mg m^{-3}) for the pot experiment. Three levels of poultry manure (PM) (0, 4 and 6 t ha^{-1}) were used in both field and pot experiments (Table 3.1). The study consisted of nine and twelve treatment combinations in the field and pot experiments respectively (Table 3.2). The soil used in the pot experiment was obtained from the same location (Anwomaso) as the field experiment.

Table 3.1: Description of treatments

Factor	**Symbol**	**Levels**
Bulk density (Soil compaction)	Bd	Bd_1: Bulk density of 1.3 Mg m^{-3} Bd_2: Bulk density of 1.5 Mg m^{-3} Bd_3: Bulk density of 1.7 Mg m^{-3} Bd_4: Bulk density of 1.9 Mg m^{-3*}
Poultry manure	PM	P_0: Poultry manure at 0 t ha^{-1} (control) P_4: Poultry manure at 4 t ha^{-1} P_6: Poultry manure at 6 t ha^{-1}

***: Additional bulk density used in pot experiment only**

Table 3.2: Treatment combinations

Treatment	Description
P_0Bd_1	P_0 + Bd_1 (Bd 1.3 Mg m^{-3} + 0 t ha^{-1} PM i.e. control)
P_0Bd_2	P_0 + Bd_2 (Bd 1.5 Mg m^{-3} + 0 t ha^{-1} PM)
P_0Bd_3	P_0 + Bd_3 (Bd 1.7 Mg m^{-3} + 0 t ha^{-1} PM)
P_4Bd_1	P_4 + Bd_1 (Bd 1.3 Mg m^{-3} + 2 t ha^{-1} PM)
P_4Bd_2	P_4 + Bd_2 (Bd 1.5 Mg m^{-3} + 2 t ha^{-1} PM)
P_4Bd_3	P_4 + Bd_3 (Bd 1.7 Mg m^{-3} + 2 t ha^{-1} PM)
P_6Bd_1	P_6 + Bd_1 (Bd 1.3 Mg m^{-3} + 4 t ha^{-1} PM)
P_6Bd_2	P_6 + Bd_2 (Bd 1.5 Mg m^{-3} + 4 t ha^{-1} PM)
P_6Bd_3	P_6 + Bd_3 (Bd 1.7 Mg m^{-3} + 4 t ha^{-1} PM)
P_0Bd_4	P_0 + Bd_4 (Bd 1.9 Mg m^{-3} + 0 t ha^{-1} PM)*
P_4Bd_4	P_4 + Bd_4 (Bd 1.9 Mg m^{-3} + 4 t ha^{-1} PM)*
P_6Bd_4	P_6 + Bd_4 (Bd 1.9 Mg m^{-3} + 6 t ha^{-1} PM)*

***: Additional treatment combinations used in pot experiment only; PM: poultry manure**

3.2.3 Experimental design and field layout

The study was a factorial experimental laid out in randomized complete block design (RCBD) for field and completely randomized design (CRD) in the pot experiment.

The treatments were replicated three times. The pot experiment was arranged on a raised wooden platform in the Plant house.

The total land area for the field experiment measured 35.0 m x 14.0 m (490.0 m^2). Each replication (block) had 9 plots, each of dimension 3.0 m x 4.0 m (12.0 m^2). Spacing between replications and plots was 1.0 m.

3.2.4 Land preparation, bulk density determination and sowing

Prior to the imposition of the compaction treatments, the field had an initial mean soil bulk density of 1.57 Mg m^{-3} before it was ploughed thoroughly and harrowed to a fine tilth. Bulk density of the field was then induced by using hand roller compactor. A Bomag BW 755 soil compactor (weight of 1025 kg) was used to establish the compaction treatments. The number of passes on the field was used as the indicator for the bulk density determination.

A core sampler was then used to obtain soil samples from each of the plot depending on the number of passes of the hand roller. The dry mass of the soils was then determined in the laboratory after oven - drying at 105 ^{0}C for 24 hours and finally, the bulk density by dividing the mass of the soil by the volume of the core sampler. The number of passes which corresponded to the appropriate bulk density was selected. The corresponding treatment plots of 1.5 and 1.7 Mg m^{-3} of soil compaction levels were compressed 5 and 7 times respectively. However, after ploughing the field, a mean soil bulk density 1.28 Mg m^{-3} was obtained and this was approximately used to represent soil compaction level of 1.3 Mg m^{-3}. The field was then lined and pegged. An 80 x 40 cm spacing was employed for sowing maize at a rate of 3 seeds/ hill and seedlings later thinned to two per hill 10 days after emergence. The overall plant population for maize was 62,500 ha^{-1}. Plates 1 and 2 shows the maize crop under different levels of soil compaction and poultry manure amendments.

Plate 1. Field experiment showing maize crop under soil compaction ($1.5\ Mg\ m^{-3}$) and PM ($6\ t\ ha^{-1}$) on a Ferric Acrisol at Anwomaso.

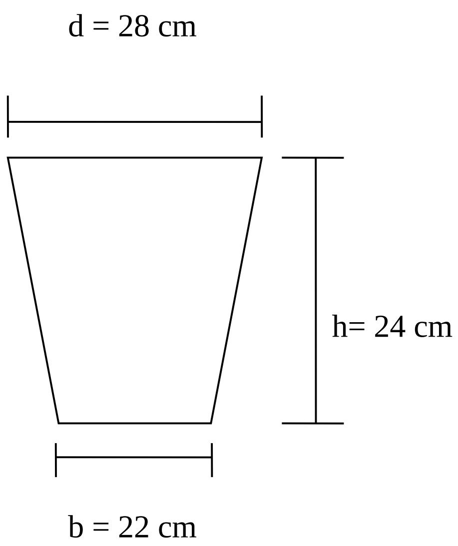
Plate 2. Field experiment showing maize crop under soil compaction ($1.7\ Mg\ m^{-3}$) and no amendement ($0\ t\ ha^{-1}$ PM) on a Ferric Acrisol at Anwomaso.

3.2.5 Pot experiment

3.2.5.1 Preparation of soil sample and standardization of bulk density

Soil from the experimental field at Anwomaso was collected and used in filling of pots. The soil used for the pot experiment was taken from a 0 -15 cm depth. A subsample was oven - dried to remove moisture for the calculation of bulk density. The volume of the pot used in the calculation was 11831.52 cm^3 whilst the height was 24 cm. Perforations were made at the bottom of the pots to allow for drainage.

Calculation:



$$\text{Volume} = \frac{\pi h}{12} \text{ x } \left(d^2 + db + b^2\right) \qquad (1)$$

where:

V = is the volume of the container

π = 3.14

d = top diameter of the frustum (28 cm)

b = bottom diameter of the frustum (22 cm)

h = height of the frustum (24 cm)

$v = (3.14 \times 24) / 12 \times (28^2 + 28 \times 22 + 22^2)$

$v = (6.28) \times (784 + 616 + 484)$

$v = 11831.52\ cm^3$

Standardizing the method of packing of the soil into the pots was necessary in order to obtain the desired bulk densities. The masses of soil to be packed into the pots to give the desired bulk densities of 1.3 Mg m^{-3}, 1.5 Mg m^{-3}, 1.7 Mg m^{-3} and 1.9 Mg m^{-3} were calculated from the expression in equation 2 (Hillel, 1995). The corresponding masses were 15.38, 17.74, 20.11 and 22.47 kg, respectively.

Calculation:

$$\rho b = \frac{M_s}{V_t} \qquad (2)$$

where:

ρb= Dry bulk density (Mg m^{-3})

M_s= Mass of dry soil (Mg)

V_t = Total volume (m^3)

Packing of weighed soils into the pots was carried out by dropping 5 kg mass from a height of 50 cm onto the soil surface completely covered with a flat wooden plate (Vickers, 1983). The mass was dropped onto the soil to obtain the required height (24 cm) used in the calculation for each soil bulk density.

Core samples were then taken after compaction using a metal cylinder and the soils dried in an oven at 105 ^oC. Bulk density was then calculated. The mean values 1.29, 1.51, 1.72, and 1.91 Mg m^{-3} were obtained from duplicate samples and were very close to the respective desired bulk densities of 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}. A total of 108 buckets were used in the pot experiment with 36 pots in each replication (comprising 3 pots for each treatment). After sowing, water loss was estimated and compensated for by weighing every 2 days and plants watered.

3.2.6 Crop husbandry practices

Poultry manure was applied by side placement to treatment plots and pots two weeks after planting (WAP) at 0, 4 and 6 t ha^{-1}. The control plots and pots did not receive any PM. The pots and plots were 'top dressed' with 30-20-20 kg ha^{-1} NPK (ie. 1/3 of the recommended rate of NPK at 90-60-60 kg ha^{-1}) at 5 WAP. The quantities of amendments applied are shown in Appendices 1 and 2. Plates 1 and 2 shows the maize crop under the different levels soil compaction and poultry manure amendments. Weed control was carried out manually with hand hoe. Lamda 2.5 EC was used for the control of insect pests.

3.3 Soil sampling

3.3.1 Initial soil characterization

Assessment of the nutrient status of the soil was carried out before cropping. Five soil samples were randomly taken at a depth of 0 – 15 cm from the plots within each block and bulked to obtain three composite samples, one for each block. These were then analysed after air – drying, crushing and sieving through a 2 mm sieve. However, for NO_3^- - N, NH_4^+ -N and microbial biomass analyses, field - moist samples were used.

3.3.2 Soil sampling during the season

For the field experiment, ten plants were randomly selected from the middle rows of each plot whilst three plants per treatment were tagged in the pot experiment for sampling purposes. Soil samples were taken near the base of each plant at a depth of 0 - 15 cm (Moore *et al.,* 2000) using auger. The samples were thoroughly mixed and sub - sampled to obtain representative sample for each plot. Fresh samples were used for microbial and mineralization analyses. In all, three samplings were made during the season at intervals of 21, 42 and 63 days after application of amendments (DAA).

3.4 Analytical methods

The physical, chemical and microbiological properties of the soils were determined in the Soil Chemistry Laboratory of the Soil Research Institute, Kwadaso, Kumasi.

3.4.1 Chemical analysis

3.4.1.1 Soil pH

Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH-meter. Approximately 20 g of soil was weighed into a 50 ml beaker and 20 ml of distilled water added to the soil. The suspension was stirred thoroughly 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 electrode into the upper part of the soil solution and the pH value recorded.

3.4.1.2 Soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten millilitres of 0.1667 *M* potassium dichromate ($K_2Cr_2O_7$) solution was added to the each flask, swirled gently so that the sample was made wet. A 20 ml concentrated sulphuric acid (H_2SO_4) was added to the soil from a measuring cylinder, swirled vigorously and allowed to stand for 30 minutes on a porcelain sheet. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 ml) was added to the mixture which was then titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

The organic carbon content of the soil was calculated as:

$$\% \text{O.C.} = \frac{\text{M x 0.39 x mcf x } (V_1 - V_2)}{w} \qquad (3)$$

where:

M = molarity of ferrous sulphate solution

V_1 = ml of ferrous sulphate solution required for blank

V_2 = ml of ferrous sulphate solution required for sample

w = weight of air-dry sample in grams

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \% \text{ moisture})}{100}$$

0.39 = 3 x 0.001 x 100 % x 1.3 (3 = equivalent mass of carbon)

1.3 = a compensation factor for the incomplete combustion of the organic carbon.

3.4.1.3 Soil total nitrogen

This was determined by the Kjeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, 5 ml concentrated sulphuric acid (H_2SO_4) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment dissolved. The solution was allowed to cool and the volume made to 100 ml with distilled water and mixed thoroughly. Ten millilitres of 40 % NaOH was added after transferring 25 ml aliquot of the solution to the reaction chamber. The solution was then distilled after which the distillate was collected in 2.0 % boric acid followed by titration with 0.02 *N* HCl. Bromocresol green was used as an indicator during the titration. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\% \text{ N} = \frac{\text{N x (a - b) x 1.4 x mcf}}{\text{w}} \qquad (4)$$

where:

N = concentration of hydrochloric acid used in titration

a = volume (ml) of hydrochloric acid used in sample titration

b = volume (ml) of hydrochloric acid used in blank titration

w = weight of air-dry sample in gram

mcf = moisture correcting factor

1.4 = 14 x 0.001 x 100 % (14 = atomic mass of nitrogen)

3.4.1.4 Bray's No.1 phosphorus (Available phosphorus)

Soil available phosphorus was determined using the Bray P_1 method (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 µg P/ml were prepared by diluting appropriate volumes of 10 µg P/ml standard sub-stock solution. These were subjected to colour development and their respective absorbance values read on a spectrophotometer at a wavelength of 660 nm. A 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 (0.03 *N* NH_4F + 0.025 *N* HCl) 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 added for colour development. The absorbance was measured at 660 nm wavelength on a spectrophotometer. The concentration of P in the extract was obtained by comparing the results with a standard curve.

Calculation:

$$\text{P mg kg}^{-1} = \frac{(\text{a - b})\text{ x } 35 \text{ x } 15 \text{ x mcf}}{\text{w}} \qquad (5)$$

where:

a = mg/l P in sample extract

b = mg/l P in blank

w = sample weight in gram

mcf = moisture correcting factor

35 = volume of extracting solution

15 = final volume of sample solution

3.4.1.5 Exchangeable cations

Exchangeable bases (calcium, magnesium potassium and sodium) on soil colloids were extracted with 1.0 *M* ammonium acetate (NH_4OAc) (Black, 1986) and exchangeable acidity (hydrogen and aluminium) determined in 1.0 *M* KCl extract as described by Page *et al*. (1982). Na^+ and K^+ ions were measured by flame photometry while Ca^{2+} and Mg^{2+} were determined by ethylenediamenetetraacetic acid (EDTA) titration.

3.4.1.5.1 Determination of exchangeable bases

A 5 g soil sample was transferred into a leaching tube and leached with 100 ml of buffered 1.0 *M* ammonium acetate solution at pH 7.

3.4.1.5.1.1 Calcium and magnesium determination

In the determination of calcium and magnesium, a 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion each of hydroxylamine hydrochloride, 2.0 % potassium cyanide buffer, 2.0 % potassium ferrocyanide, 10.0 ml ethanolamine buffer and, 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01 *M* EDTA to a pure turquoise blue colour. A 20 ml 0.01 *M* magnesium chloride solution was also titrated with 0.01 *M* EDTA in the presence of 25 ml of 1.0 *M* ammonium acetate solution to provide a standard blue colour for the titration.

3.4.1.5.1.2 Determination of calcium

A millilitre each of hydroxylamine hydrochloride, 2 % potassium cyanide and potassium ferrocyanide solutions were added to a 25 ml portion of the extract in a 250 ml Erlenmeyer flask. After a few minutes, 5 ml of 8 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 *M* EDTA solution to a pure blue colour.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\mathrm{Ca} + \mathrm{Mg}\left(\mathrm{or\ Ca}\right)\left(\mathrm{cmol}_{(c)}\ \mathrm{kg}^{-1}\ \mathrm{soil}\right) = \frac{0.01\ \mathrm{x}\ \left(\mathrm{V_a} - \mathrm{V_b}\right)\mathrm{x}\ 1000}{\mathrm{w}} \qquad (6)$$

where:

w = weight (g) of air – dried soil used

V_a = ml of 0.01 *M* EDTA used in sample titration

V_b = ml of 0.01 *M* EDTA used in blank titration

0.01= concentration of EDTA

3.4.1.5.1.3 Determination of exchangeable potassium and sodium

The flame photometry procedure was used in the determination of potassium (K) and sodium (Na) in the leachate. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each solution into 250 ml volumetric flasks and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH_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 leachate by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

Calculations:

$$\text{Excheageable K (cmol}_{(+)}\text{ kg}^{-1}\text{ soil)} = \frac{(a - b)\text{ x } 250\text{ x mcf}}{10\text{ x } 39.1\text{ x w}} \quad (7)$$

$$\text{Exchangeable Na (cmol}_{(+)}\text{ kg}^{-1}\text{ soil)} = \frac{(a - b)\text{ x } 250\text{ x mcf}}{10\text{ x } 23\text{ x w}} \quad (8)$$

where:

a = mg/l K or Na in the diluted sample percolate

b = mg/l K or Na in the diluted blank percolate

w = weight (g) of air- dried sample

mcf = moisture correcting factor

3.4.1.5.2 Determination of exchangeable acidity (Al^{3+} and H^+)

The Al^{3+} + H^+ was extracted from the soil sample with unbuffered 1.0 *M* KCl followed by titration. Ten grams of soil sample was weighed into a 200 ml bottle and 50 ml of 1.0 *M* KCl solution added. The bottle was capped and shaken for 1.0 hour and the mixture filtered. Twenty-five millilitres portion of the extract was taken with a pipette into a 250 ml Erlenmeyer flask and 4 – 5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 *M* NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmol}_{(+)}\text{ kg}^{-1}\text{ soil)} = \frac{(a - b)\text{ x M x 2 x } 100\text{ x mcf}}{\text{w}} \quad (9)$$

where:

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air- dried sample

2 = 50/25 (filtrate/ pipetted volume)

mcf = moisture correcting factor (100 + % moisture)/100

3.4.1.5.3 Effective cation exchange capacity (ECEC)

This was determined by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and exchangeable acidity ($Al^{3+} + H^+$).

3.4.1.6 Mineral N determinations

3.4.1.6.1 Determination of nitrate -nitrogen (NO_3^- -N)

Nitrate in the soil sample was determined by extraction with 0.5 *M* K_2SO_4. Ten grams of fresh soil was shaken for 30 minutes in 30 ml of extractant (0.5 *M* K_2SO_4). The solution was filtered through Whatman No. 42 filter paper and nitrate in the clear solution determined by the colorimetric method. A 2 ml aliquot of the extract was pipetted into a test tube. To this was added 1 ml salicylic acid solution prepared by dissolving 5 g salicylic acid in 95 ml concentrated sulphuric acid (Anderson and Ingram, 1998). The resulting solution was allowed to stand for 30 minutes after which 10 ml of 4.0 *M* sodium hydroxide solution was added and mixed thoroughly. Following 1 hour of full colour development, the absorbance of the yellow colour was read at a wavelength of 410 nm on a spectronic 21 D spectrophotometer.

A standard series of 0, 2, 4, 6 and 8 mg/l NO_3^- -N was prepared in 50 ml volumetric flasks from a 50 mg/l NO_3^- -N stock solution. The absorbance for each standard was then read on the spectrophotometer. A standard curve was obtained by plotting a graph of absorbance against standard concentrations. The solution concentrations for sample and blank were determined from the curve. The blank value was then subtracted from the sample value to give a value for corrected concentration, C.

Calculation:

$$NO_3^- \text{ - N}\left(\text{mg kg}^{-1}\text{ soil}\right) = \frac{\text{C x V}}{\text{W}} \qquad (10)$$

where:

C = corrected concentration (mg/l)

V= extract volume (ml)

W = weight of sample (g)

3.4.1.6.2 Determination of ammonium - nitrogen (NH_4^+-N)

The NH_4^+ -N in the soil was determined from the same extract as NO_3^- -N above. A 2 ml aliquot of the extract was pipetted into a test tube to which two different reagents (RI and RII) were added. RI was prepared by mixing three separately prepared solutions namely: 4 % EDTA (5 ml), 0.05 g/ml sodium nitroprussite (100 ml) and 1.12 g/ml sodium salicylate (50 ml). RII was prepared by dissolving 0.2 g of sodium dichlorocyanate in 10 ml of distilled water and transferred to a 200 ml flask. The volume was made up to the mark with a buffer solution of 0.0746 *M* $Na_2HPO_4.12H_2O$ (adjusted to pH 12.3). The resulting solution was allowed to stand for 2 hours after the addition of 3 ml and 5 ml of RI and RII, respectively.

Working standards of 0, 5, 10, 15 and 20 mg/l were prepared from 1 g/l NH_4^+ -N stock solution. The absorbance of the sample, blank and working standards were read on the spectrophotometre at a wavelength of 660 nm. A graph of absorbance against standard concentrations was plotted. Solution concentrations for the sample and blank were then determined. The blank value was subtracted from the sample value to give a value for corrected concentration, C.

Calculation:

$$NH_4^+ \text{ - N} \left(\text{mg kg}^{-1} \text{ soil}\right) = \frac{\text{C x V}}{\text{W}} \qquad (11)$$

where:

C = corrected concentration (mg/l)

V= extract volume (ml)

W = weight of sample (g)

3.4.1.7 Determination of soil microbial biomass

3.4.1.7.1 Soil microbial carbon and nitrogen

The method of chloroform fumigation and extraction (FE) as described by Ladd and Amato (1989) was used to determine the microbial biomass. Ten grams field - moist soil sample, after passing through a 4 mm mesh, was put in a crucible and placed in a desiccator. A shallow dish containing 30 ml of alcohol – free chloroform was placed by it. A crucible containing a control sample (10 g) was placed in a separate desiccator without chloroform. The desiccators were covered and allowed to stand at room temperature for 5 days (Anderson and Ingram, 1998).

Immediately after fumigation, 50 ml of 0.5 *M* K_2SO_4 solution was added to the soil samples to extract microbial carbon and nitrogen from the lysed microorganisms. Total nitrogen in the extract was then determined by the Kjeldahl method. The amount of microbial carbon in the extract was determined using the colorimetric method. An aliquot (5 ml) of the extract was pipetted into 250 ml Erlenmeyer flask. To this were added 5 ml of 1.0 *N* (0.1667 *M*) potassium dichromate and 10 ml concentrated sulphuric acid. The resulting solution was allowed to cool for 30 minutes after which 10 ml of distilled water was added. A standard series was developed concurrently with carbon concentrations ranging from 0, 2.5, 5.0, 7.5, 10.0 mg/ml C. These concentrations were obtained when volumes of 0, 5, 10, 15 and 20 ml of a 50 mg/ml C stock were pipetted into labelled 100 ml volumetric flasks and made up to the mark with distilled water. The absorbances of the standard and sample solutions were read on a spectronic 21D spectrophotometre at a wavelength of 600 nm. A standard curve was obtained by plotting absorbance values of the standard solutions against their corresponding concentrations. Extracted carbon concentration of the samples was determined from the standard curve. For biomass C and N calculations, k -factors of 0.35 (Sparling *et al.* 1990) and 0.45 (Jenkinson, 1988; Ross and Tate, 1993) were used, respectively. The following equations according to Sparling and West (1998) were used to estimate the microbial C and N from the extracted C and N respectively:

Microbial C (mg) = E_C / k

Microbial N (mg) = E_N / k

where:

E_N = the extracted nitrogen produced following fumigation

E_C = the extracted carbon produced following fumigation

k = the fraction of the killed biomass extracted as carbon or nitrogen under standardized conditions

3.4.1.7.2 Soil microbial phosphorus

For microbial biomass P analysis, 5 g of field-moist soil was weighed into a crucible and fumigated in a dessicator with 30 ml of alcohol-free chloroform for 5 days. Both fumigated and unfumigated soil samples were shaken with 35 ml Bray's No.1 extracting solution (0.03 *M* NH_4F + 0.025 *M* HCl) for 10 minutes and filtered.

Correction for adsorption of P during fumigation was made by simultaneously equilibrating unfumigated soil with a series of P containing standard solutions followed by extraction with the Bray-1 solution. The amount of chloroform released P was determined according to the relationship between P added (from standard solutions or microbial lysis) and P extracted by the Bray-1 solution (Oberson *et al.*, 1997). Phosphorus adsorption during equilibrium is described by the following equation according to Barrow and Shaw (1975) and adapted by Morel *et al*. (1997):

$$Ext_p = Ext_0 + b_1 Pad^{b2}$$

where:

Ext_p = Pi concentration (mg/l) extracted after equilibration with different amounts of P added

Ext_0 = Pi concentration extracted without P addition,

b_1, b_2 = coefficients estimated by non- linear regression of mean values of Extp against Pad

Pad = amount of P added (0 - 20 mg kg^{-1})

Chloroform released P corresponds to P addition and was calculated from the equation:

$$P_{chl}. = [(Ext_{chl} - Ext_0)/b1]^{1/b2}$$

where:

$P_{chl.}$ = chloroform released P (mg kg^{-1}).

Ext_{chl}= Pi concentration in extracts of fumigated samples.

The amount of microbial P was estimated by assuming a kp factor of 0.4 (Brookes *et al.*, 1982; McLaughlin and Alston, 1986).

3.4.2 Soil physical analyses

3.4.2.1 Particle size analysis

Soil texture was determined by the hydrometer method (Boyoucos, 1962). Fifty grammes of air-dried soil was weighed into a measuring cylinder and 50 ml of sodium hexamethaphosphate (calgon) added. The suspension was shaken and allowed to stand. Corrected hydrometer readings at 40 seconds and 5 hours were taken.

Calculation:

% sand = 100 – [(A / W) × 100]

% clay = 100 × (B/ W)

% silt = 100 – (% sand + % clay)

where:

A= corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 5 hours

W = weight of dry soil

The textural class was then determined from the textural triangle.

3.4.2.2 Soil bulk density

Soil bulk density in the field at 0 – 15 cm depth was determined by the core method described by Blake and Hartge (1986). A cylindrical core sampler of diameter 6.8 cm and height 20 cm was used to sample undisturbed soil. The core was driven to the desired depth (0 – 15 cm) and the soil sample carefully removed.

The soil was then weighed, dried at 105 ^{o}C for two days and reweighed. Bulk density was calculated as:

$$\rho b\left(\mathrm{Mg\,m^{-3}}\right)=\frac{\text{mass of dry soil sample}\left(M_s\right)}{\text{volume of soil}\left(V_t\right)} \qquad (12)$$

where:

ρb = soil bulk density (Mg m^{-3})

M_s = mass of the oven dry soil (Mg)

V_t = total volume of soil (m^3)

3.4.2.3 Gravimetric water content (θm)

The gravimetric method was used to determine the water content of the soil before compacting to the various bulk densities. Ten (10) grams of the soil was dried in an oven at 105 ^oC for 24 hours. The dry mass of the soil was taken after drying and this was subtracted from the initial mass to obtain the mass of water lost.

Calculation:

$$\theta m = \frac{M_w}{M_s} \text{ x } 100 \quad (13)$$

where:

M_w = mass of water lost (g)

M_s = mass of dry soil (g)

3.4.2.4 Hydraulic conductivity

A 40 cm^3 metallic core cylinder was half - filled with soil from the field and the saturated hydraulic conductivities determined in the laboratory using the modified falling head method. The time taken for every 2 cm drop in water level from the tube was recorded. The In$\frac{H0}{Ht}$ was plotted against time t (s).

where:

H_0: Initial height of the water level in the cylinder

Ht: Final height after the 2 cm drop in the water level.

The slope of the graph is given by $\frac{Ks}{L}$.

where:

Ks: Saturated hydraulic conductivity

L: Length of the soil column.

Ks = slope × L

3.4.2.5 Porosity

Porosity of the soil was determined using the expression below:

$$\% f = \left(1 - \frac{\rho b}{\rho s}\right) x\, 100 \qquad (14)$$

where:

ρb = bulk density (Mg m^{-3})

f = total porosity (%)

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

3.5 Poultry manure characterization

The poultry manure used in the study was obtained from Ayigya poultry farms, near KNUST Police Station in the Ashanti region. Before application, a representative sample was taken, dried in the oven at 40 ^{o}C (Anderson and Ingram, 1998) and ground to pass through a 1 mm sieve. The chemical properties were determined to assess the quality of the manure.

3.5.1 Nitrogen

Twenty grams (20 g) oven-dried sample was ground in a mill and passed through a 1 mm sieve. A 0.5 g sample was digested in a 10 ml concentrated sulphuric acid with selenium mixture as catalyst. The resulting clear digest was transferred into a 100 ml conical flask and made to volume with distilled water. A 5 ml aliquot of the sample and a blank were pipetted into the Kjeldahl distillation apparatus separately and 10 ml of 40 % NaOH solution added followed by distillation. The evolved ammonia gas was trapped in a 25 ml of 2 % boric acid. The distillate was titrated with 0.1 *M* HCl using bromocresol green-methyl red as indicator (Soils Laboratory Staff, 1984).

Calculation:

$$\% \text{ N/DM} = \frac{(\text{a - b}) \text{ x } M \text{ x } 1.4 \text{ x mcf}}{\text{w}} \qquad (15)$$

where:

a = ml HCl used for sample titration

b = ml HCl used for blank titration

M = molarity of HCl

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

DM = dry matter

w = weight of sample

3.5.2 Organic carbon

Organic carbon content of the poultry manure was determined using the dichromate-acid oxidation method. Ten millilitres (10 ml) each of concentrated sulphuric acid, 0.5 *N* potassium dichromate solution and concentrated orthophosphoric acid were added to 0.05 g of sample in Erlenmeyer flask. The solution was allowed to stand for 30 minutes after addition of distilled water. It was then back titrated with 0.5 *N* ferrous sulphate solution using diphenylamine indicator.

Calculation:

$$\% \text{ carbon } = \frac{\text{N x } (\text{a - b}) \text{ x } 3 \text{ x } 10^{-3} \text{ x } 100 \text{ x } 1.3}{\text{w}} \qquad (16)$$

where:

N = normality of ferrous sulphate

a = ml ferrous sulphate solution required for sample titration

b = ml ferrous sulphate solution required for blank titration

w = weight of oven- dried sample in gram

3 = equivalent weight of carbon

1.3 = compensation factor allowing for incomplete combustion

3.5.3 Phosphorus, potassium, sodium, calcium and magnesium

A 0.5 g mass of poultry manure was ashed in a muffle furnace, after which the ash was dissolved in 1.0 *M* HCl solution and filtered. The filtrate was then diluted to 100 ml with distilled water.

3.5.3.1 Phosphorus

A 5 ml aliquot of the filtrate was placed into a 25 ml volumetric flask. Five millilitres of ammonium vanadate solution and 2 ml stannous chloride solution were added. The volume was made up to 25 ml with distilled water and allowed to stand for 15 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P/kg organic material. The absorbance of the sample and standard solutions were read on a spectronic 21D spectrophotometre at a wavelength of 470 nm. The absorbance values of the standard solutions were plotted against their respective concentrations to obtain a standard curve from which phosphorus concentrations of the samples were determined.

3.5.3.2 Potassium and sodium

Potassium and sodium in the leachate were determined using a Gallenkamp flame analyzer. Standard solutions of potassium and sodium were prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg/litre of solution. The emission values which were read on flame analyzer were plotted against their respective concentrations to obtain standard curves.

3.5.3.3 Calcium and magnesium

A 10 ml aliquot of the ash solution was pipetted into an Erlenmeyer flask. One millilitre each of potassium cyanide and potassium ferrocyanide solutions were added to complex interfering cations like Cu and Fe. To determine calcium + magnesium concentration, the solution was titrated with 0.01 *M* EDTA solution in the presence of Eriochrome Black T indicator. In calcium determination, potassium hydroxide solution (5 ml) was added to raise the pH to 12 so as to precipitate magnesium, leaving calcium in solution. The solution was titrated with EDTA using murexide as indicator. The difference between the first and second titres represents magnesium concentration in the solution.

3.5.4 Polyphenols

Polyphenol content was determined as described by Anderson and Ingram (1998). One gram of dried, milled and sieved poultry manure was weighed into 50 ml separate conical flasks. Ethanol (20 ml) was added to the organic material and heated to 60 ^{o}C to extract the polyphenol. The extraction was repeated after the alcohol extract was decanted into another flask. After the third extraction, the volume of the extract was made to 50 ml by adding ethanol. Standard solutions of tannic acid (with concentrations of 0, 20, 40, 80 and 100 mg tannic acid per litre) were prepared. The samples and tannic acid standards were subjected to colour development. Absorbance values of the standard and sample solutions were read on spectrophotometre at a wavelength of 760 nm. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions and used to determine sample solution concentrations.

Calculation:

mg kg^{-1} polyphenol = graph reading × sample dilution × aliquot dilution

where:

sample dilution = final volume/weight of sample = 50/1

aliquot dilution = 50/1 (1 ml of initial 50 ml extract was put in a 50 ml flask and made to the 50 ml mark with ethanol. i.e. 50/1)

3.5.5 Determination of organic fraction (soluble) and lignin

3.5.5.1 Soluble organic fraction (lipids and sugars)

One gram of organic residue was extracted for 1 hour with 20 ml of ethanol: benzene (1:1, v: v) in a sealed pyrex tube at 60 ^{o}C, which was then cooled and centrifuged. The procedure was repeated twice and the combined extract evaporated slightly and the volume made to 50 ml in a flask of which 10 ml aliquot was taken for dry weight determination. The dry weight represented lipid fraction (Kachaka *et al.,* 1993). The residue was hydrolyzed with 25 ml of 1.0 *N* sulphuric acid in a sealed pyrex tube at 100 ^{o}C for 1 hour, cooled and centrifuged. The supernatant solution was saved in another container and the process repeated with two washings of distilled water to remove most of the sulphuric acid from the residue. A 10 ml aliquot was taken for dry weight determination which was considered as the sugar fraction.

3.5.5.2 Lignin

After the alcohol and dilute sulphuric acid extraction, 2 ml of 72 % sulphuric acid was added to the residue and shaken for 4 hours. The solution was transferred into a 100 ml Erlenmeyer flask with 40 ml distilled water, boiled for 2 hours and filtered. Sugar which represents cellulose was determined in the hydrolysate. The residue was washed with water, dried at 60 ^{o}C for 48 hours, weighed and then ashed in a muffle furnace.

The lignin content of the residue was considered as the loss in weight on ignition (Anderson and Ingram, 1998).

3.6 Plant parameters measured

3.6.1 Plant height

Five plants were randomly selected from each treatment plot tagged and their heights measured using a measuring tape. Measurements were taken 2, 4, 6, 8 and 10 weeks after planting (WAP).

3.6.2 Straw/ stover weight

At the twelfth-leaf stage of vegetative growth (V12 or at tasselling), three plants from each plot or pot were cut from the ground level and oven-dried at 70 ^{o}C to a constant weight. At physiological maturity (R6), three plants were cut from each plot or pot and separated into ear (cobs + grains) and stover (husks + leaves + stem) and oven - dried at 70 ^{o}C to a constant weight.

3.6.3 Plant sampling and analysis

Three maize plants at V12 were sampled from each plot and pot for plant tissue analysis. Samples were cut from the ground level, washed with tap water and distilled water, dried at room temperature for three days and oven-dried at 70 ^{o}C to constant weight before grinding with a Wiley mill to pass through a 0.5 mm sieve. The samples were chemically analyzed to determine their nitrogen content. Concentration of N was expressed on a dry weight basis and the nutrient uptake and accumulation calculated using the respective plant dry weights.

For R6, samples were divided into ear (grains and cobs) and stover (husk, leaves and stem) and analyzed separately for their nitrogen concentrations.

Nitrogen uptake was then computed from the expression:

$$\text{N uptake (kg ha}^{-1}\text{) = N contents (\%) in plant part (dry matter) x Yield (kg ha}^{-1}\text{)} \quad (17)$$

where yield represents biomass (stover) or grain/ ear yield

3.6.4 Grain yield and hundred seed weight

Cobs were harvested, de-husked, shelled and weighed from each plot and pot. This was done to determine grain yield at harvest in kg ha^{-1}. Hundred seed weight per plot or pot was determined by counting 100 seeds in each treatment plot or pot and the weight in grammes determined.

3.7 Data analysis

The data collected were analysed using the Genstat (2009) statistical package. The least significant difference (LSD) method at 5 % probability was used to separate treatment means. Regression and correlation analyses were also carried out to determine the nature and magnitude of relationships between and among key parameters.

CHAPTER FOUR

4.0 RESULTS

4.1 Initial soil properties

To assess the fertility status of the soil at the experimental site, initial characterization of the soil was carried out and the results are shown in Table 4.1.

Table 4.1. Initial soil properties of the study site

Soil property	Min	Max	Mean	SD	CV
MBC (mg C kg^{-1} soil)	274.59	411.92	343.26	97.11	28.29
MBN (mg N kg^{-1} soil)	104.01	156.03	130.02	36.78	28.29
MBP (mg P kg^{-1} soil)	20.61	42.10	31.36	15.20	48.47
NO_3^- -N (mg N kg^{-1} soil)	3.51	4.80	4.16	0.91	21.88
NH_4^+ -N (mg N kg^{-1} soil)	10.56	11.30	11.00	0.52	4.72
pH (1: 1, H_2O)	5.65	6.17	5.91	0.37	6.26
OC (%)	1.17	1.54	1.36	0.26	19.12
Total N (%)	0.12	0.14	0.13	0.01	7.69
Available P (mg kg^{-1})	3.98	6.25	5.12	1.61	31.45
Exchangeable cations ($cmol_{(+)}$ kg^{-1} soil)					
Ca^{2+}	3.74	4.01	3.88	0.19	4.89
Mg^{2+}	1.34	1.60	1.47	0.18	12.24
K^+	0.12	0.14	0.13	0.01	7.69
Na^+	0.07	0.09	0.08	0.01	12.5
$Al^{3+} + H^+$	0.08	0.10	0.09	0.01	11.11
ECEC ($cmol_{(+)}$ kg^{-1} soil)	5.35	5.94	5.65	0.42	7.43
Sand (%)	64.84	66.68	65.76	1.30	1.98
Silt (%)	29.16	29.32	29.24	0.11	0.38
Clay (%)	4.00	6.00	5.00	1.41	28.20
Soil texture	Sandy loam				
Soil bulk density (Mg m^{-3})	1.55	1.58	1.57	0.02	1.27

CV: coefficient of variation (%), SD: standard deviation, MBC: microbial biomass carbon, MBN: microbial biomass nitrogen, MBP: microbial biomass phosphorus, OC: organic carbon, values are means of duplicate samples.

The soil pH ranged from 5.65 to 6.17 with a CV < 7 %. Soil OC and total N values ranged between 1.17 - 1.54 % and 0.12 - 0.14 % respectively.

The recorded available P values varied between 3.98 to 6.25 mg kg^{-1}. The mean NO_3^- -N value recorded was < 5.0 mg kg^{-1} soil whilst that of NH_4^+ -N was > 10.0 mg kg^{-1} soil. Chemical properties such as pH, total nitrogen, exchangeable K^+ and Ca^{2+}, and ECEC exhibited less variability (CV < 10 %). Initial bulk density varied between 1.55 and 1.58 Mg m^{-3}. The soil texture of the study site (Anwomaso) was sandy loam.

4.2 Poultry manure characterization

Characterization of poultry manure was carried out to determine its nutrient composition before application. The results indicated mean values of 2.15 %, 0.90 % and 0.50 % for total N, P and K, respectively (Table 4.2). The mean C: N and C: P ratios were less than 25 and 50 respectively. Mean lignin: N ratio and polyphenol: N ratios recorded were respectively less than 12 and 2 (Table 4.2).

Table 4.2. Chemical properties of poultry manure applied during the experiment

Chemical property	Min	Max	Mean	SD	CV
Total nutrient (%)					
N	2.10	2.20	2.15	0.07	3.26
P	0.87	0.93	0.90	0.04	4.44
K	0.49	0.50	0.50	0.01	2.00
Ca	3.20	3.34	3.27	0.10	3.06
Mg	0.19	0.21	0.20	0.01	5.00
Polyphenol (%)	3.31	3.46	3.39	0.11	3.24
Lignin	24.49	25.00	24.75	0.36	1.45
OC (%)	43.75	45.78	44.77	1.44	3.22
C:N ratio	20.80	20.81	20.81	0.01	0.05
C:P ratio	49.23	50.28	49.76	0.74	1.49
Lignin:N ratio	11.37	11.66	11.52	0.21	1.82
Polyphenol:N ratio	1.48	1.57	1.53	0.06	3.92

CV: coefficient of variation (%), SD: standard deviation, OC: organic carbon.

4.3 Impact of poultry manure amendment and soil compaction on mineral nitrogen dynamics

4.3.1 Soil nitrate - nitrogen

In the field experiment, significant differences were generally observed (P < 0.05) between soil compaction and amendment levels on soil NO_3^- -N at 21, 42 and 63 days after amendment (DAA) (Table 4.3a). Levels of NO_3^- -N registered an increase from 21 to 42 DAA, and was followed by a drastic decline at 63 DAA. There were significant (P < 0.05) amendment x compaction interaction effect on NO_3^- -N at 21 and 42 DAA but not at 63 DAA (Table 4.3a). The recorded amendment x compaction interaction values ranged from 7.10 – 61.90 mg N kg^{-1} soil with P_6Bd_1 generally producing the highest values.

As observed in the field experiment, NO_3^- -N increased in the pot experiment from 21 to 42 DAA and declined at 63 DAA. However, significant difference (P < 0.05) between amendments on soil NO_3^- -N was observed only at 21 DAA (Table 4.3b). The unamended plots (0 t ha^{-1} PM) generally recorded the lowest values of NO_3^- -N at 21, 42 and 63 DAA in both field and pot experiments. The impact of compaction on NO_3^- -N levels was significant (P < 0.05) only at 63 DAA. Like the field experiment, there were significant amendment x compaction interaction (P < 0.05) on NO_3^- -N during the periods of sampling with values ranging from 8.20 – 52.99 mg N kg^{-1} soil (Table 4.3b).

Table 4.3a: Impact of poultry manure amendment and soil compaction on nitrate - nitrogen (Field experiment)

Treatments	**NO_3^- -N (mg N kg^{-1} soil)**		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	36.09	42.00	9.97
4	50.30	53.80	10.27
6	52.27	56.20	9.48
LSD (0.05)	8.77	9.28	NS
CV (%)	8.40	8.10	8.60
Soil bulk density (Mg m^{-3})			
1.3	49.24	52.60	10.57
1.5	46.29	48.90	8.05
1.7	43.12	50.40	11.11
LSD (0.05)	3.94	NS	2.01
CV (%)	4.60	8.70	6.30
Interaction			
P_0Bd_1	34.96	40.40	10.70
P_0Bd_2	36.74	38.70	7.10
P_0Bd_3	36.57	46.90	12.10
P_4Bd_1	54.21	55.60	11.62
P_4Bd_2	52.39	54.40	9.62
P_4Bd_3	44.29	51.30	9.59
P_6Bd_1	58.56	61.90	9.40
P_6Bd_2	49.75	53.70	7.42
P_6Bd_3	48.50	52.80	11.63
LSD (0.05)	9.11	10.67	NS
CV (%)	8.30	10.80	19.80

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}

Table 4.3b: Impact of poultry manure amendment and soil compaction on nitrate - nitrogen (Pot experiment)

Treatments	**NO_3^- -N (mg N kg^{-1} soil)**		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	23.73	34.91	8.78
4	43.96	49.57	11.13
6	47.92	49.96	10.34
LSD (0.05)	4.85	NS	NS
CV (%)	5.50	15.10	4.20
Soil bulk density (Mg m^{-3})			
1.3	37.45	46.72	10.76
1.5	40.39	46.69	10.16
1.7	38.92	44.17	9.75
1.9	37.39	41.66	9.67
LSD (0.05)	NS	NS	0.64
CV (%)	4.40	15.20	8.40
Interaction			
P_0Bd_1	24.52	34.94	9.59
P_0Bd_2	25.69	35.20	8.60
P_0Bd_3	22.42	32.51	8.20
P_0Bd_4	22.29	36.99	8.72
P_4Bd_1	38.40	42.41	12.62
P_4Bd_2	45.72	52.99	11.45
P_4Bd_3	43.68	51.03	9.76
P_4Bd_4	48.03	51.85	10.70
P_6Bd_1	49.23	47.63	10.06
P_6Bd_2	49.76	51.89	10.42
P_6Bd_3	46.25	48.98	11.30
P_6Bd_4	46.43	51.33	9.59
LSD (0.05)	9.31	15.29	1.92
CV (%)	15.20	11.70	6.40

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

4.3.2 Ammonium - nitrogen

In the field experiment, plots amended with both 4 and 6 t ha^{-1} poultry manure produced NH_4^+ -N values which were significantly different ($P < 0.05$) from that of the control plots (0 t ha^{-1}) at 21 and 42 DAA except at 63 DAA (Table 4.3c). In the pot experiment, significant differences ($P < 0.05$) in NH_4^+ -N levels under the amendments were observed at 42 and 63 DAA but not at 21 DAA (Table 4.3d). At 42 DAA, soil compaction x amendment interactions significantly influenced ($P < 0.05$) levels of soil NH_4^+ -N in both experiments. On the 42nd day after amendment, the highest level of the parameter was observed in the field experiment under bulk density of 1.3 Mg m^{-3} and poultry manure at 6 t ha^{-1} (Table 4.3c) whilst the lowest was recorded under bulk density of 1.7 Mg m^{-3} and poultry manure rate of 0 t ha^{-1} (control) (Table 4.3d).

Levels of NH_4^+ -N followed similar trends as that of NO_3^- -N levels in the field experiment with increases from 21 to 42 DAA, and a sharp decline at 63 DAA (Table 4.3c). In contrast, NH_4^+ -N levels in the pot experiment decreased slightly from 21 to 42 DAA, followed by a sharp decline at 63 DAA (Table 4.3d). Comparatively, levels of NO_3^- -N were higher than that of NH_4^+ -N in both experiments.

Table 4.3c: Soil ammonium - nitrogen as influenced by poultry manure amendment and soil compaction (Field experiment)

Treatments	**NH_4^+ -N (mg N kg^{-1} soil)**		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	12.56	28.81	7.57
4	14.55	33.57	7.06
6	15.57	33.24	10.51
LSD (0.05)	1.62	3.47	1.96
CV (%)	5.00	4.80	18.10
Soil bulk density (Mg m^{-3})			
1.3	14.55	32.49	8.05
1.5	13.75	31.93	6.90
1.7	14.37	31.21	10.19
LSD (0.05)	NS	NS	2.49
CV (%)	2.40	2.00	10.30
Interaction			
P_0Bd_1	13.91	29.03	8.54
P_0Bd_2	11.68	30.45	5.96
P_0Bd_3	12.10	26.93	8.21
P_4Bd_1	13.95	31.64	6.25
P_4Bd_2	15.29	34.15	5.69
P_4Bd_3	14.41	34.93	9.25
P_6Bd_1	15.80	36.78	9.37
P_6Bd_2	14.29	31.17	9.05
P_6Bd_3	16.61	31.77	13.11
LSD (0.05)	NS	4.34	NS
CV (%)	14.90	7.50	28.90

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05 P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}

Table 4.3d: Soil ammonium - nitrogen as influenced by poultry manure amendment and soil compaction (Pot experiment)

Treatments	NH_4^+ -N (mg N kg^{-1} soil)		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	14.58	13.13	7.31
4	22.16	19.04	6.83
6	20.85	20.31	8.94
LSD (0.05)	NS	5.24	1.11
CV (%)	16.40	13.20	7.80
Soil bulk density (Mg m^{-3})			
1.3	18.12	17.87	7.95
1.5	20.26	19.27	7.23
1.7	19.95	15.63	8.39
1.9	18.46	17.20	7.20
LSD (0.05)	NS	NS	0.91
CV (%)	9.90	10.00	6.40
Interaction			
P_0Bd_1	13.40	14.60	8.78
P_0Bd_2	15.02	13.26	6.63
P_0Bd_3	15.29	11.96	6.47
P_0Bd_4	14.62	12.72	7.36
P_4Bd_1	18.47	18.49	6.32
P_4Bd_2	24.30	21.09	6.35
P_4Bd_3	23.68	17.29	7.92
P_4Bd_4	22.18	19.28	6.73
P_6Bd_1	22.47	20.52	8.76
P_6Bd_2	21.47	23.47	8.72
P_6Bd_3	20.86	17.66	10.78
P_6Bd_4	18.58	19.60	7.50
LSD (0.05)	NS	6.00	1.59
CV (%)	12.50	16.90	12.00

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

4.3.3 Soil NH_4^+ -N: NO_3^- -N ratio

Results of ammonium to nitrate - nitrogen ratios are presented in Tables 4.3e and 4.3f. Generally, poultry manure, soil compaction and their interactions did not significantly influence (P > 0.05) the ratios in both field and pot experiments.

Table 4.3e: NH_4^+ -N: NO_3^- -N ratios as affected by poultry manure amendment and soil compaction (Field experiment)

Treatments	**NH_4^+ -N : NO_3^- -N ratio**		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	0.35	0.70	0.77
4	0.29	0.64	0.70
6	0.30	0.60	1.15
LSD (0.05)	NS	NS	NS
CV (%)	9.80	9.30	18.50
Soil bulk density (Mg m^{-3})			
1.3	0.31	0.63	0.79
1.5	0.30	0.68	0.90
1.7	0.34	0.62	0.93
LSD (0.05)	NS	NS	NS
CV (%)	6.30	7.00	15.20
Interaction			
P_0Bd_1	0.40	0.72	0.81
P_0Bd_2	0.31	0.79	0.84
P_0Bd_3	0.34	0.59	0.66
P_4Bd_1	0.26	0.57	0.54
P_4Bd_2	0.29	0.66	0.61
P_4Bd_3	0.33	0.68	0.96
P_6Bd_1	0.27	0.60	1.03
P_6Bd_2	0.29	0.58	1.24
P_6Bd_3	0.34	0.60	1.17
LSD (0.05)	NS	NS	NS
CV (%)	13.80	13.10	23.60

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.3f: NH_4^+ -N: NO_3^- -N ratios as affected by poultry manure amendment and soil compaction (Pot experiment)

Treatments	NH_4^+ -N : NO_3^- -N ratio		
Poultry manure (t ha^{-1})	21 DAA	42 DAA	63 DAA
0	0.63	0.39	0.83
4	0.52	0.39	0.63
6	0.44	0.40	0.87
LSD (0.05)	NS	NS	NS
CV (%)	14.10	3.60	15.00
Soil bulk density (Mg m^{-3})			
1.3	0.51	0.43	0.76
1.5	0.53	0.41	0.73
1.7	0.56	0.37	0.86
1.9	0.51	0.37	0.75
LSD (0.05)	NS	0.05	NS
CV (%)	15.10	5.10	5.40
Interaction			
P_0Bd_1	0.55	0.43	0.92
P_0Bd_2	0.60	0.37	0.78
P_0Bd_3	0.68	0.40	0.79
P_0Bd_4	0.68	0.35	0.84
P_4Bd_1	0.52	0.43	0.50
P_4Bd_2	0.53	0.40	0.56
P_4Bd_3	0.55	0.34	0.82
P_4Bd_4	0.46	0.37	0.63
P_6Bd_1	0.46	0.43	0.87
P_6Bd_2	044	0.45	0.85
P_6Bd_3	0.46	0.36	0.97
P_6Bd_4	0.40	0.38	0.79
LSD (0.05)	NS	NS	0.27
CV (%)	24.90	12.10	12.40

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

Specifically, levels of compaction under pot experiment significantly influenced ($P < 0.05$) the NH_4^+ -N: NO_3^- -N ratios at 42 DAA (Table 4.3f). At 63 DAA, significant differences ($P < 0.05$) were only observed in the pot experiment under amendment x compaction interactions with P_6Bd_3 producing the highest NH_4^+ -N: NO_3^- -N ratio of 0.97. NH_4^+ -N: NO_3^- -N ratio in the pot experiment decreased from 21 to 42 DAA, and later increased at 63 DAA. In contrast, NH_4^+ -N: NO_3^- -N ratio followed an increasing pattern from 21 to 63 DAA in the field experiment.

4.4 Effect of poultry manure application and soil compaction on soil microbial biomass carbon and nitrogen

Soil microbial biomass carbon and nitrogen were generally influenced ($P < 0.05$) by poultry manure amendment at 42 DAA (Tables 4.4a and 4.4b). Biomass C under amendments ranged from 54.93 - 89.14 mg kg^{-1} soil and 50.74 – 93.64 mg kg^{-1} soil in field and pot experiments, respectively (Tables 4.4a and 4.4b). Plots amended with 4 t ha^{-1} produced significantly higher ($P < 0.05$) microbial biomass carbon than the control plots (0 t ha^{-1}) but was not significantly different ($P > 0.05$) from plots amended with 6 t ha^{-1} in both experiments. The different levels of soil compaction produced statistically similar effects ($P > 0.05$) on microbial biomass carbon.

Biomass N under the amendments ranged from 16.71 - 28.85 mg kg^{-1} soil and 17.73 – 27.87 mg kg^{-1} soil in field and pot experiments respectively (Tables 4.4a and 4.4b). Like biomass carbon, plots amended with 4 t ha^{-1} produced significantly higher ($P < 0.05$) microbial biomass nitrogen than the control plots. Bulk density x amendment interacted significantly ($P < 0.05$) to influence MBC and MBN in both experiments, such that P_4Bd_1 recorded the highest MBC values whilst P_6Bd_1 produced the highest MBN values (Tables 4.4a and 4.4b).

Table 4.4a: Effect of poultry manure application, compacted soil levels and their interactions on MBC and MBN at 42 DAA (Field experiment)

Treatments	MBC (mg C kg^{-1} soil)	MBN (mg N kg^{-1} soil)
Poultry manure (t ha^{-1})	42 DAA	42 DAA
0	54.93	16.71
4	89.14	28.85
6	88.65	28.61
LSD (0.05)	4.44	3.52
CV (%)	2.50	6.30
Soil bulk density (Mg m^{-3})		
1.3	79.44	25.78
1.5	76.55	23.41
1.7	76.72	24.98
LSD (0.05)	NS	NS
CV (%)	0.70	6.30
Interaction		
P_0Bd_1	56.12	16.77
P_0Bd_2	54.56	15.86
P_0Bd_3	54.10	17.49
P_4Bd_1	92.74	30.01
P_4Bd_2	88.39	26.68
P_4Bd_3	86.30	27.85
P_6Bd_1	89.47	30.55
P_6Bd_2	86.70	25.89
P_6Bd_3	89.77	29.60
LSD (0.05)	6.32	5.61
CV (%)	4.90	14.10

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, MBC: Microbial biomass carbon, MBN: Microbial biomass nitrogen, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.4b: Effect of poultry manure application, compacted soil levels and their interactions on MBC and MBN (Pot experiment)

Treatments	MBC (mg C kg^{-1} soil)	MBN (mg N kg^{-1} soil)
Poultry manure (t ha^{-1})	42 DAA	42 DAA
0	50.74	17.73
4	93.64	27.87
6	89.32	25.89
LSD (0.05)	13.72	5.62
CV (%)	7.80	10.40
Bulk density (Mg m^{-3})		
1.3	79.89	24.62
1.5	79.58	23.68
1.7	79.95	24.81
1.9	72.18	22.23
LSD (0.05)	NS	NS
CV (%)	4.60	14.00
Interaction		
P_0Bd_1	56.72	19.01
P_0Bd_2	55.81	16.73
P_0Bd_3	50.43	18.79
P_0Bd_4	39.99	16.40
P_4Bd_1	95.94	25.48
P_4Bd_2	92.17	29.72
P_4Bd_3	98.50	29.73
P_4Bd_4	87.95	26.57
P_6Bd_1	87.00	29.36
P_6Bd_2	90.76	24.57
P_6Bd_3	90.93	25.91
P_6Bd_4	88.59	23.71
LSD (0.05)	14.29	5.98
CV (%)	7.50	10.90

LSD: Least significant difference at 5 %, Coefficient of variation (CV), DAA: Days after amendment, NS: Not significant at P = 0.05, MBC: Microbial biomass carbon, MBN: Microbial biomass nitrogen, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

The results in Tables 4.4c and 4.4d revealed significant correlations between some biological and chemical parameters measured. A significant positive correlation was observed between MBC and SOC in both experiments (r = 0.964* and 0.998*) (Table 4.4c) and between MBN and total nitrogen (r = 0.622* and 0.999*) (Table 4.4c). Similarly, positive correlation was also observed between MBN and mineralized N (NH_4^+ -N and NO_3^- -N) in both experiments (Table 4.4d).

Table 4.4c: Coefficients of correlation (r) between MBC, MBN and some selected chemical parameters as influenced by poultry manure application

Dependent parameter (y) (mg kg^{-1} soil)	Independent parameter (x) (%)	r
MBC (Field experiment)	Organic carbon	0.964*
MBC (Pot experiment)	Organic carbon	0.998*
MBN (Field experiment)	Total nitrogen	0.622*
MBN (Pot experiment)	Total nitrogen	0.999*

*Significant at P < 0.05, MB: microbial biomass, MBN: microbial biomass nitrogen, MBC: microbial biomass carbon, C: carbon, N: nitrogen.

Table 4.4d: Coefficients of correlation (r) between MBN and mineralized N (NH_4^+ -N and NO_3^- -N) as influenced by poultry manure application

Dependent parameter (y) (mg kg^{-1} soil)	Independent parameter (x) (mg kg^{-1} soil)	r
MBN (Field experiment)	Nitrate – N	0.985
MBN (Pot experiment)	Nitrate – N	0.979*
MBN (Field experiment)	Ammonium – N	0.999
MBN (Pot experiment)	Ammonium – N	0.939

*Significant at P < 0.05, MBN: microbial biomass nitrogen, N: nitrogen

4.5 Soil compaction effects on porosity and saturated hydraulic conductivity

Results of the impact of bulk density on hydraulic conductivity and total porosity are presented in Tables 4.5a and 4.5b. Saturated hydraulic conductivity decreased with increasing soil bulk density ranging, from 1.2 x 10^{-2} to 4.5 x 10^{-3} cm/s at 1.3 Mg m^{-3} and 1.7 Mg m^{-3} in the field experiment (Table 4.5a) and between 1.2 x 10^{-2} and 3.0 x 10^{-3} cm/s at 1.3 Mg m^{-3} and 1.9 Mg m^{-3} in the pot experiment (Table 4.5b). Specifically, hydraulic conductivity decreased by 50, 62.5 and 75 % as soil bulk density increased from 1.3 to 1.5, 1.7 and 1.9 Mg m^{-3} in the pot experiment.

Total porosity followed similar trend as hydraulic conductivity. The total porosity of the soil decreased from 51 to 36 % when bulk density increased from 1.3 to 1.7 Mg m^{-3} in the field experiment and from 51 to 28 % when bulk density increased from 1.3 to 1.9 Mg m^{-3} in the pot experiment.

Table 4.5a: Impact of bulk density on saturated hydraulic conductivity and total porosity (field experiment)

Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm/s)	Total porosity (%)
1.3	1.2 x 10^{-2}	51
1.5	6.0 x 10^{-3}	43
1.7	4.5 x 10^{-3}	36

Table 4.5b: Impact of bulk density on saturated hydraulic conductivity and total porosity (pot experiment)

Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm/s)	Total porosity (%)
1.3	1.2×10^{-2}	51
1.5	6.0×10^{-3}	43
1.7	4.5×10^{-3}	36
1.9	3.0×10^{-3}	28

The hydraulic conductivity graph of $\ln\frac{Ho}{HT}$ against time for bulk densities of 1.3, 1.5, 1.7 Mg m^{-3} and 1.3, 1.5, 1.7, 1.9 Mg m^{-3} respectively in the field and pot experiments showed strong positive coefficient of determination (R^2) ranging from 0.998 – 1.000 (Appendix 2).

4.6 Impact of poultry manure and soil compaction on soil properties at harvest

Tables 4.6a and 4.6b show the effects of poultry amendment and bulk density on soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable potassium contents of the soil at the end of the experiment.

From the results obtained, application of poultry manure significantly influenced the soil pH, organic carbon and exchangeable K in the field experiment and that of the soil pH, organic carbon and available P in the pot experiment. The application of PM led to an increase in soil pH, organic carbon, total N and available P contents (Tables 4.6a and 4.6b) over the initial values recorded (Table 4.1).

Table 4.6a: Impact of poultry manure amendment and soil compaction on selected soil chemical parameters after harvest (Field experiment)

Treatment	pH	Organic carbon (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K ($cmol_{(+)}kg^{-1}$)
Poultry manure (t ha^{-1})					
0	5.72	1.17	0.14	13.20	0.12
4	5.95	1.54	0.15	20.20	0.16
6	6.25	1.62	0.14	10.80	0.12
LSD (0.05)	0.24	0.04	NS	NS	0.02
CV (%)	2.00	3.30	3.60	35.50	34.70
Soil bulk density (Mg m^{-3})					
1.3	6.00	1.43	0.14	11.30	0.14
1.5	5.97	1.32	0.15	20.00	0.13
1.7	5.95	1.29	0.14	12.90	0.13
LSD (0.05)	NS	NS	NS	NS	NS
CV (%)	1.80	3.90	1.20	41.20	6.90
Interaction					
P_0Bd_1	5.74	1.19	0.14	7.90	0.09
P_0Bd_2	5.67	1.14	0.16	20.20	0.15
P_0Bd_3	5.76	1.12	0.14	11.30	0.12
P_4Bd_1	5.98	1.61	0.15	20.20	0.19
P_4Bd_2	5.83	1.55	0.15	23.60	0.14
P_4Bd_3	6.04	1.43	0.13	16.90	0.14
P_6Bd_1	6.27	1.63	0.14	5.80	0.13
P_6Bd_2	6.43	1.62	0.14	16.00	0.10
P_6Bd_3	6.06	1.53	0.15	10.60	0.11
LSD (0.05)	0.28	0.05	NS	NS	NS
CV (%)	2.50	10.90	10.30	59.30	39.60

LSD: Least significant difference at 5 %, Coefficient of variation (CV), NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1= 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.6b: Impact of poultry manure amendment and soil compaction on selected soil chemical parameters after harvest (Pot experiment)

Treatment	pH	Organic carbon (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K ($cmol_{(+)}$ kg^{-1})
Poultry manure (t ha^{-1})					
0	5.70	1.21	0.15	8.23	0.11
4	6.08	1.51	0.15	13.82	0.17
6	6.29	1.61	0.16	12.49	0.13
LSD (0.05)	0.33	0.03	NS	2.34	NS
CV (%)	1.00	2.08	13.2	9.90	21.80
Soil bulk density (Mg m^{-3})					
1.3	6.11	1.48	0.17	12.10	0.15
1.5	6.01	1.44	0.15	11.69	0.12
1.7	5.95	1.40	0.14	12.14	0.13
1.9	6.02	1.37	0.15	10.12	0.14
LSD (0.05)	NS	0.05	NS	NS	NS
CV (%)	2.50	4.00	8.50	9.00	16.80
Interaction					
P_0Bd_1	5.74	1.29	0.16	7.92	0.10
P_0Bd_2	5.67	1.26	0.15	8.78	0.09
P_0Bd_3	5.76	1.23	0.14	7.98	0.12
P_0Bd_4	5.62	1.22	0.13	8.24	0.12
P_4Bd_1	6.31	1.61	0.22	13.87	0.19
P_4Bd_2	5.93	1.55	0.15	12.29	0.17
P_4Bd_3	6.04	1.43	0.14	16.23	0.14
P_4Bd_4	6.05	1.44	0.15	12.89	0.17
P_6Bd_1	6.27	1.65	0.14	14.51	0.17
P_6Bd_2	6.43	1.62	0.15	14.01	0.11
P_6Bd_3	6.06	1.59	0.15	12.22	0.12
P_6Bd_4	6.40	1.57	0.15	9.23	0.14
LSD (0.05)	0.35	0.05	NS	NS	NS
CV (%)	2.40	9.70	29.20	21.90	31.00

LSD: Least significant difference at 5 %, Coefficient of variation (CV), NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

Soil compaction did not significantly influence organic C, total N, available P and exchangeable K contents of the soil. However, the impact of compaction on the soil chemical composition after harvest recorded an increase in total N, organic carbon and available P contents over the initial values (Table 4.1). Soil pH and organic carbon were significantly influenced ($P < 0.05$) by the main effect of poultry manure. The interaction between soil compaction and poultry manure significantly influenced pH and organic carbon in both experiments but not soil total N, available P and exchangeable K.

As expected, the application of poultry manure resulted in a reduction in soil bulk density in both experiments (Tables 4.6c and 4.6d). At high compaction levels (1.7 and 1.9 Mg m^{-3}), a compensatory effect was observed with a high application rate of 6 t ha^{-1} PM. Unamended plots recorded an increase in bulk density across all soil compaction levels over the initial value. Conversely, the compensatory effect of the application of 4 and 6 t ha^{-1} PM generally decreased soil bulk density by 1.3 – 2.4 % and 0.6 – 1.2 % respectively in both field and pot experiments relative to the initial levels of compaction (Tables 4.6c and 4.6d). The interactive effects of P_4Bd_3 and P_6Bd_3 in the field experiment recorded the highest reduction of 2.4 % in bulk density value over the initial value (1.7 Mg m^{-3}).

Table 4.6c: Compensatory effect of poultry manure on soil compaction levels after harvest in field experiment

Treatment Amendment x compaction	Bulk density ($Mg\ m^{-3}$)
P_0Bd_1	1.35
P_0Bd_2	1.56
P_0Bd_3	1.70
P_4Bd_1	1.30
P_4Bd_2	1.48
P_4Bd_3	1.66
P_6Bd_1	1.33
P_6Bd_2	1.47
P_6Bd_3	1.66
LSD (0.05)	0.03
CV (%)	1.10

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.6d: Compensatory effect of poultry manure on soil compaction levels after harvest in pot experiment

Treatment Amendment x compaction	Bulk density ($Mg\ m^{-3}$)
P_0Bd_1	1.31
P_0Bd_2	1.53
P_0Bd_3	1.71
P_0Bd_4	1.92
P_4Bd_1	1.29
P_4Bd_2	1.48
P_4Bd_3	1.69
P_4Bd_4	1.90
P_6Bd_1	1.29
P_6Bd_2	1.49
P_6Bd_3	1.68
P_6Bd_4	1.88
LSD (0.05)	0.02
CV (%)	0.60

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

4.7 Impact of poultry manure amendment and soil compaction on N uptake of maize

At V12, poultry manure applied at the rate of 6 t ha^{-1} led to the highest N uptake of 137.20 kg ha^{-1} and 95.10 kg ha^{-1} respectively in maize stover in field and pot experiments (Tables 4.7a and 4.7b). The control plots recorded the lowest N uptake. Nitrogen uptake in stover was in the decreasing order of 6 > 4 > 0 t ha^{-1}.

The highest N uptake in the field experiment was recorded under bulk density of 1.5 Mg m^{-3} at V12 which was not statistically different ($P > 0.05$) from plots with bulk density of 1.3 Mg m^{-3} (Table 4.7a). On the other hand, the highest N uptake in the pot experiment was recorded in plots with soil bulk density of 1.3 Mg m^{-3} at V12. Bulk density x amendment interacted significantly to influence N uptake with the highest values recorded under P_6Bd_1 and P_6Bd_2 in the pot and field experiments, respectively. The least N uptake was observed under P_0Bd_2 and P_0Bd_4 respectively in the field and pot experiments. Increasing the rate of amendment led to increased uptake of N in maize stover under increasing levels of soil compaction at V12 indicating the compensatory effect of the poultry manure for N uptake.

Table 4.7a: Impact of poultry manure amendment and soil compaction on N uptake at V12 and R6 growth stages of maize (Field experiment)

Treatments	V12	R6	
	Stover N Uptake	Stover N Uptake	Ear N Uptake
Poultry manure(t ha^{-1})	**(kg ha^{-1})**	**(kg ha^{-1})**	**(kg ha^{-1})**
0	69.00	35.10	43.50
4	116.80	88.50	117.50
6	137.20	96.70	112.60
LSD (0.05)	24.54	5.71	12.45
CV (%)	10.10	3.40	6.00
Soil bulk density (Mg m^{-3})			
1.3	114.00	83.20	98.20
1.5	114.30	68.40	89.60
1.7	94.70	68.60	85.70
LSD (0.05)	25.37	5.91	6.90
CV (%)	15.80	4.80	2.80
Interaction			
P_0Bd_1	73.30	37.10	43.70
P_0Bd_2	66.60	33.10	43.90
P_0Bd_3	67.20	35.00	42.80
P_4Bd_1	129.70	100.50	126.30
P_4Bd_2	130.20	80.70	118.00
P_4Bd_3	90.40	84.20	108.20
P_6Bd_1	139.00	112.00	124.70
P_6Bd_2	146.00	91.60	107.00
P_6Bd_3	126.60	86.60	106.10
LSD (0.05)	39.53	9.23	13.81
CV (%)	22.90	7.80	7.40

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.7b: Impact of poultry manure amendment and soil compaction on N uptake at V12 and R6 growth stages of maize (Pot experiment)

Treatments	V12	R6	
Poultry manure(t ha^{-1})	Stover N Uptake (kg ha^{-1})	Stover N Uptake (kg ha^{-1})	Ear N Uptake (kg ha^{-1})
0	39.50	21.14	28.65
4	86.50	52.14	80.66
6	95.10	55.06	87.63
LSD (0.05)	9.57	6.13	4.46
CV (%)	5.70	6.30	3.00
Bulk density (Mg m^{-3})			
1.3	86.90	48.77	71.14
1.5	73.50	44.20	70.43
1.7	73.50	42.35	64.43
1.9	60.90	35.81	56.58
LSD (0.05)	7.00	1.99	4.32
CV (%)	7.80	3.60	1.70
Interaction			
P_0Bd_1	43.40	23.58	33.46
P_0Bd_2	36.50	21.45	29.84
P_0Bd_3	43.40	20.59	27.90
P_0Bd_4	34.70	18.95	23.39
P_4Bd_1	107.20	59.49	88.39
P_4Bd_2	85.80	55.61	82.64
P_4Bd_3	80.60	50.96	79.07
P_4Bd_4	72.40	42.51	72.54
P_6Bd_1	110.00	63.24	91.56
P_6Bd_2	98.30	55.52	98.82
P_6Bd_3	96.40	55.50	86.33
P_6Bd_4	75.60	45.96	73.81
LSD (0.05)	12.69	6.10	7.21
CV (%)	9.60	4.70	6.60

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

At R6, application of poultry manure at a rate of 6 t ha^{-1} led to the highest N uptake in maize stover in both experiments (Tables 4.7a and 4.7b) whilst the control plots produced the lowest N uptake.

On the other hand, the highest stover N uptakes of 83.20 kg ha^{-1} and 48.77 kg ha^{-1} were respectively obtained in field and pot experiments under soil bulk density of 1.3 Mg m^{-3}.

Bulk density x amendment interaction affected stover N uptake in both experiments. At R6 however, increased level of soil compaction generally decreased N uptake at increasing rate of poultry manure amendment. Ear N uptake increased with the application of poultry manure from 0 to 6 t ha^{-1} in the pot experiment (Table 4.7b) and increased under application of 0 to 4 t ha^{-1} in the field experiment after which there was a decline from 4 to 6 t ha^{-1} (Table 4.7a).

4.8 Plant height and stover dry weight as affected by soil compaction and poultry manure amendment

Levels of soil compaction and poultry manure amendment significantly influenced maize plant height. At 6, 8 and 10 WAP, poultry manure amendment of 4 t ha^{-1} produced taller plants than the control and plots under 6 t ha^{-1} treatment in the field experiment (Table 4.8a). In the pot experiment, however, poultry manure amendment at 6 t ha^{-1} produced significantly ($P < 0.05$) taller maize plants than the control and plots under 4 t ha^{-1} treatment except at 6 WAP (Table 4.8b). Interestingly, plant height under application of 4 t ha^{-1} PM was not significantly different ($P > 0.05$) from that under 6 t ha^{-1} in both experiments (Tables 4.8a and 4.8b).

Soil compaction significantly ($P < 0.05$) influenced plant height at all periods of sampling (Tables 4.8a and 4.8b). At 10 WAP, plant height ranged from 217.90 - 232.31 cm and 170.21 – 177.91 cm respectively in field and pot experiments. Soil bulk density of 1.3 Mg m^{-3} significantly produced the highest plant height values. Throughout the various stages of sampling, bulk density x amendment interaction significantly affected plant height except at 2 WAP in both field and pot experiments.

Table 4.8a: Impact of poultry manure amendment and soil compaction and their interactions on plant height (Field experiment)

Treatments	**Mean plant height (cm)**				
Poultry manure (t ha^{-1})	2WAP	4WAP	6WAP	8WAP	10WAP
0	18.72	37.73	84.91	170.20	203.91
4	18.40	44.30	119.91	227.30	237.66
6	18.48	44.31	117.24	218.20	231.20
LSD (0.05)	NS	3.12	11.99	6.87	10.88
CV (%)	2.60	3.30	4.90	1.50	2.10
Soil bulk density (Mg m^{-3})					
1.3	20.81	46.31	119.04	220.70	232.31
1.7	18.11	41.30	106.29	202.50	222.56
1.7	16.68	38.73	96.73	192.40	217.90
LSD (0.05)	1.08	1.41	4.52	5.70	3.78
CV (%)	3.90	2.70	0.80	0.20	0.70
Interaction					
P_0Bd_1	21.03	42.53	93.33	181.70	208.93
P_0Bd_2	18.60	36.73	84.80	169.30	205.07
P_0Bd_3	16.53	39.93	76.60	159.50	197.73
P_4Bd_1	20.27	49.53	132.47	249.10	247.73
P_4Bd_2	17.93	43.17	117.60	222.50	232.67
P_4Bd_3	17.00	40.20	109.67	210.30	232.57
P_6Bd_1	21.13	46.87	131.33	231.30	240.27
P_6Bd_2	17.80	44.00	116.47	215.70	229.93
P_6Bd_3	16.50	42.07	103.93	207.60	223.40
LSD (0.05)	NS	3.25	12.05	9.42	10.82
CV (%)	5.70	3.30	4.10	2.70	1.60

LSD: Least significant difference at 5 %, Coefficient of variation (CV), NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.8b: Impact of poultry manure amendment and soil compaction and their interactions on plant height (Pot experiment)

Treatments	**Mean plant height (cm)**				
Poultry manure (t ha^{-1})	2WAP	4WAP	6WAP	8WAP	10WAP
0	25.82	44.92	78.43	124.52	154.18
4	25.20	46.82	98.64	153.86	184.03
6	25.73	47.91	98.45	154.07	184.69
LSD (0.05)	NS	1.50	4.06	1.68	2.58
CV (%)	4.00	1.40	2.00	0.50	0.70
Soil bulk density (Mg m^{-3})					
1.3	27.89	48.60	98.33	147.91	177.91
1.5	24.91	45.77	93.09	144.87	175.40
1.7	25.13	46.46	89.39	143.22	173.67
1.9	24.39	45.38	86.56	140.59	170.21
LSD (0.05)	2.14	1.32	3.51	1.26	1.33
CV (%)	1.40	1.10	2.20	0.30	0.50
Interaction					
P_0Bd_1	29.50	45.20	81.80	129.83	157.20
P_0Bd_2	24.87	43.80	81.27	125.50	155.13
P_0Bd_3	25.33	45.87	76.73	122.90	153.90
P_0Bd_4	23.57	44.83	73.93	119.83	150.47
P_4Bd_1	26.33	48.60	107.13	156.17	189.03
P_4Bd_2	24.23	46.33	99.40	154.60	183.93
P_4Bd_3	24.30	46.20	95.70	154.80	183.80
P_4Bd_4	25.93	46.13	92.33	149.87	179.33
P_6Bd_1	27.83	52.00	106.07	157.73	187.50
P_6Bd_2	25.63	47.17	98.60	154.50	187.13
P_6Bd_3	25.77	47.30	95.73	151.97	183.30
P_6Bd_4	23.68	45.17	93.40	152.07	180.83
LSD (0.05)	NS	2.25	6.03	2.26	2.86
CV (%)	8.40	2.90	3.90	0.90	0.80

LSD: Least significant difference at 5 %, Coefficient of variation (CV), NS: Not significant at P = 0.05, P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

The analysis of variance (ANOVA) revealed that poultry manure amendment, soil compaction and their interaction significantly ($P < 0.05$) affected stover dry weight at both stages of growth in both experiments (Tables 4.8c and 4.8d). Similarly, ear dry weight was significantly influenced at R6.

In the field experiment, dry stover weight values at V12 were 3354, 6119 and 7323 kg ha^{-1} under application of 0 (control), 4 and 6 t ha^{-1} of poultry manure respectively (Table 4.8c) and 2030, 4495 and 4668 kg ha^{-1} corresponding to application levels of 0 (control), 4 and 6 t ha^{-1} PM in the pot experiment (Table 4.8d). Dry stover weight under poultry manure application was in the increasing order of $0 < 4 < 6$ t ha^{-1}. The values recorded under application of 4 and 6 t ha^{-1} PM did not differ significantly from each other but were significantly different ($P < 0.05$) from the control. At R6, dry stover weight and ear dry weight followed similar trends as dry stover weight at V12.

Dry stover weight values at V12 under the different levels of soil compaction ranged from 5328 - 5977 kg ha^{-1} and 3287 - 4080 kg ha^{-1} in field and pot experiments respectively. Dry stover weight produced under bulk density of 1.3 Mg m^{-3} was significantly higher than that of 1.5 and 1.7 Mg m^{-3} in the field experiment (Table 4.8c). The influence of bulk density on plant dry weight in the pot experiment was in the decreasing order of $1.3 > 1.5 > 1.7 > 1.9$ Mg m^{-3} (Table 4.8d).

Bulk density and poultry amendments interacted significantly ($P < 0.05$) to affect dry weight in the field and pot experiments at both V12 and R6.

Table 4.8c: Maize dry weight at V12 and R6 as affected by poultry manure amendment and soil compaction (Field experiment)

Treatments	V12	R6	R6
Poultry manure (t ha^{-1})	Stover dry weight (kg ha^{-1})	Stover dry weight (kg ha^{-1})	Ear dry weight (kg ha^{-1})
0	3354.00	2364.00	1900.00
4	6119.00	5514.00	4446.00
6	7323.00	5586.00	4501.00
LSD (0.05)	1457.10	90.70	118.10
CV (%)	11.50	0.90	1.40
Soil bulk density (Mg m^{-3})			
1.3	5977.00	4726.00	3924.00
1.7	5490.00	4489.00	3521.00
1.7	5328.00	4248.00	3402.00
LSD (0.05)	429.10	79.70	182.20
CV (%)	13.20	0.60	2.30
Interaction			
P_0Bd_1	3771.00	2414.00	2043.00
P_0Bd_2	3057.00	2379.00	1848.00
P_0Bd_3	3235.00	2300.00	1811.00
P_4Bd_1	6376.00	5864.00	4719.00
P_4Bd_2	6318.00	5494.00	4444.00
P_4Bd_3	5662.00	5184.00	4174.00
P_6Bd_1	7785.00	5901.00	5008.00
P_6Bd_2	7095.00	5595.00	4273.00
P_6Bd_3	7088.00	5260.00	4222.00
LSD (0.05)	1432.00	129.80	268.60
CV (%)	7.50	1.70	4.90

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.8d: Maize dry weight at V12 and R6 as affected by poultry manure amendment and soil compaction (Pot experiment)

Treatments	V12	R6	R6
Poultry manure(t ha^{-1})	Stover dry weight (kg ha^{-1})	Stover dry weight (kg ha^{-1})	Ear dry weight (kg ha^{-1})
0	2030.00	1624.00	1242.00
4	4495.00	3596.00	3071.00
6	4668.00	3734.00	3245.00
LSD (0.05)	467.10	373.70	169.00
CV (%)	5.50	5.50	3.00
Soil bulk density (Mg m^{-3})			
1.3	4080.00	3264.00	2756.00
1.5	3863.00	3090.00	2581.00
1.7	3694.00	2955.00	2522.00
1.9	3287.00	2630.00	2219.00
LSD (0.05)	169.00	135.20	127.30
CV (%)	5.10	5.10	2.60
Interaction			
P_0Bd_1	2193.00	1755.00	1423.00
P_0Bd_2	2048.00	1638.00	1285.00
P_0Bd_3	2021.00	1617.00	1226.00
P_0Bd_4	1859.00	1487.00	1036.00
P_4Bd_1	4923.00	3938.00	3343.00
P_4Bd_2	4740.00	3792.00	3034.00
P_4Bd_3	4382.00	3506.00	3098.00
P_4Bd_4	3936.00	3149.00	2810.00
P_6Bd_1	5124.00	4099.00	3502.00
P_6Bd_2	4800.00	3840.00	3425.00
P_6Bd_3	4680.00	3744.00	3242.00
P_6Bd_4	4066.00	3253.00	2810.00
LSD (0.05)	471.20	376.90	228.30
CV (%)	4.60	4.60	5.10

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

4.9 Grain yield and 100 seed weight of maize as affected by poultry manure amendment and soil compaction

As expected, total grain yield as observed in the field experiment was relatively higher than that of the pot experiment under both amendments and soil compaction levels (Tables 4.9a and 4.9b). Poultry manure and soil compaction significantly influenced ($P < 0.05$) grain yield. Poultry manure applied at the rate of 6 t ha^{-1} produced the highest grain yield of 3004 and 2453 kg ha^{-1} in field and pot experiment respectively but were not significantly different ($P > 0.05$) from values recorded under application of 4 t ha^{-1}.

The highest grain yield was recorded under bulk density of 1.3 Mg m^{-3} in both field and pot experiments which was significantly higher than values observed under soil bulk densities of 1.5, 1.7 and 1.9 Mg m^{-3}. From the data, there was a 10 % decrease in grain yield in 1.5 Mg m^{-3} and 12 % in 1.7 Mg m^{-3} as compared to soil bulk density of 1.3 Mg m^{-3} (Table 4.9a). On the other hand, there was a 10 %, 16 % and 23 % decline in grain yields under bulk densities of 1.5, 1.7 and 1.9 Mg m^{-3} respectively relative to grain yield produced under 1.3 Mg m^{-3}. Interaction between poultry manure amendment and soil compaction significantly affected ($P < 0.05$) grain yield in both experiments. Interaction between P_6 and Bd_1 produced the highest grain yields in the field and pot experiments.

Like grain yield, hundred seed weight (HSW) was significantly influenced by amendment and soil compaction. Treatments amended with poultry manure produced significantly higher values ($P < 0.05$) than that of the unamended plot (Tables 4.9a and 4.9b). Poultry manure at the rate of 4 t ha^{-1} produced the highest 100 seed weight of 19.90 g but was not significantly different ($P > 0.05$) from HSW under application rate of 6 t ha^{-1} in the field experiment (Table 4.9a). The highest HSW in the pot experiment was obtained from the application of 6 t ha^{-1} and was also not significantly different ($P > 0.05$) from the value recorded under application of 4 t ha^{-1} poultry manure (Table 4.9b).

Table 4.9a: Impact of poultry manure amendment and soil compaction and their interactions on grain yield and 100 seed weight (Field experiment)

Treatments	Grain yield (kg ha^{-1})	100 Seed weight (g)
Poultry manure (t ha^{-1})		
0	1280.00	14.44
4	3000.00	19.90
6	3004.00	19.73
LSD (0.05)	116.10	0.57
CV (%)	2.10	1.40
Soil bulk density (Mg m^{-3})		
1.3	2621.00	18.62
1.5	2361.00	17.74
1.7	2302.00	17.71
LSD (0.05)	119.00	0.38
CV (%)	2.80	1.70
Interaction		
P_0Bd_1	1383.00	14.75
P_0Bd_2	1240.00	14.32
P_0Bd_3	1217.00	14.24
P_4Bd_1	3160.00	20.23
P_4Bd_2	2980.00	19.77
P_4Bd_3	2860.00	19.70
P_6Bd_1	3320.00	20.87
P_6Bd_2	2863.00	19.15
P_6Bd_3	2830.00	19.19
LSD (0.05)	336.00	0.70
CV (%)	4.80	2.10

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3= 1.7 Mg m^{-3}

Table 4.9b: Impact of poultry manure amendment and soil compaction and their interactions on grain yield and 100 seed weight (Pot experiment)

Treatments	Grain yield (kg ha^{-1})	100 Seed weight (g)
Poultry manure (t ha^{-1})		
0	1047.00	11.24
4	2423.00	19.50
6	2453.00	19.85
LSD (0.05)	192.00	0.42
CV (%)	4.30	1.10
Soil bulk density (Mg m^{-3})		
1.3	2251.00	17.33
1.5	2024.00	17.01
1.7	1891.00	16.94
1.9	1730.00	16.19
LSD (0.05)	84.10	0.25
CV (%)	2.00	1.10
Interaction		
P_0Bd_1	1130.00	11.76
P_0Bd_2	1067.00	11.38
P_0Bd_3	1033.00	11.28
P_0Bd_4	957.00	10.56
P_4Bd_1	2730.00	19.89
P_4Bd_2	2493.00	19.55
P_4Bd_3	2313.00	19.56
P_4Bd_4	2153.00	19.00
P_6Bd_1	2893.00	20.33
P_6Bd_2	2513.00	20.10
P_6Bd_3	2327.00	19.97
P_6Bd_4	2080.00	19.00
LSD (0.05)	201.80	0.60
CV (%)	4.30	1.50

LSD: Least significant difference at 5 %, Coefficient of variation (CV), P_0 = 0 t PM ha^{-1}, P_4 = 4 t PM ha^{-1}, P_6 = 6 t PM ha^{-1}, Bd_1 = 1.3 Mg m^{-3}, Bd_2 = 1.5 Mg m^{-3}, Bd_3 = 1.7 Mg m^{-3}, Bd_4 = 1.9 Mg m^{-3}

Soil compaction significantly influenced ($P < 0.05$) 100 seed weight of maize. The highest HSW values of 18.62 g and 17.33 g in field and pot experiments respectively were recorded under bulk density of 1.3 Mg m^{-3} (Tables 4.9a and 4.9b). HSW observed under soil bulk densities of 1.5 and 1.7 Mg m^{-3} were not significantly different ($P > 0.05$) from each other.

4.10 Relationship between selected plant parameters.

Correlation analysis in both experiments among plant height, above ground biomass dry weight, total tissue N and N uptake at V12 and R6 are shown in Tables 4.10a - 4.10d. At V12, N uptake (%) correlated positively with plant height and stover dry weight (Tables 4.10a and 4.10b). At R6, there was a general significant positive correlation between growth and yield parameters measured (Tables 4.10c and 4.10d).

Table 4.10a: Pearson correlation coefficients (r) between maize agronomic parameters at V12 growth stage of maize (Field experiment)

	Plant height (cm)	Dry Weight (kg ha^{-1})	Plant N (%)	N uptake (kg ha^{-1})
Plant height	1			
Stover dry weight	0.75*	1		
Plant N	NS	NS	1	
N uptake	0.70*	0.85*	NS	1

*: Significant at $P < 0.05$, NS: not significant

Table 4.10b: Pearson correlation coefficients (r) between maize agronomic parameters at V 12 growth stage of maize (Pot experiment)

	Plant height (cm)	Dry Weight (kg ha^{-1})	Plant N (%)	N uptake (kg ha^{-1})
Plant height	1			
Stover dry weight	0.96*	1		
Plant N	NS	NS	1	
N uptake	0.91*	0.95*	0.43*	1

*: Significant at P < 0.05, NS: not significant

Table 4.10c: Pearson correlation coefficients (r) between maize agronomic parameters at R6 (Field experiment)

	Sto. dry wt. (kg ha^{-1})	Sto. N uptake (kg ha^{-1})	Ear dry wt. (kg ha^{-1})	Ear N uptake (kg ha^{-1})	Total dry wt. (kg ha^{-1})	Grain yield (kg ha^{-1})	HSW (g)
Sto. dry wt.	1						
Sto. N uptake	0.97*	1					
Ear dry wt.	0.99*	0.97*	1				
Ear N uptake	0.98*	0.94*	0.98*	1			
Total dry wt.	1.00*	0.97*	1.00*	0.98*	1		
Grain yield	0.99*	0.97*	1.00*	0.98*	1.00*	1	
HSW	0.98*	0.96*	0.98*	0.97*	0.98*	0.98*	1

*: Significant at P < 0.05, NS: not significant, Sto: stover, wt.: weight, HSW: 100 seed weight

Table 4.10d: Pearson correlation coefficients between maize agronomic parameters as affected by soil compaction and poultry manure amendment at R6 (Pot experiment)

	Sto. dry wt. (kg ha^{-1})	Sto. N uptake (kg ha^{-1})	Ear dry wt. (kg ha^{-1})	Ear N uptake (kg ha^{-1})	Total dry wt. (kg ha^{-1})	Grain yield (kg ha^{-1})	HWS (g)
Sto. dry wt.	1						
Sto. N uptake	0.99*	1					
Ear dry wt.	0.97*	0.97*	1				
Ear N uptake	0.97*	0.96*	0.99*	1			
Total dry wt.	0.99*	0.99*	0.99*	0.99*	1		
Grain yield	0.97*	0.98*	0.97*	0.96*	0.98*	1	
HSW	0.96*	0.95*	0.99*	0.98*	0.98*	0.96*	1

*: Significant at P < 0.05, Sto: stover, wt.: weight, HSW: 100 seed weight

CHAPTER FIVE

5.0 DISCUSSION

5.1 Initial soil properties of the study site

Soil pH is a key soil parameter that provides an overview of the overall chemical properties of the soil especially in plant nutrient availabilty. The pH of the soil was moderately acidic (Schoenebeger *et al*., 2002). This is attributable to moderate leaching of basic cations out of the top soil as evidenced by the low ECEC (Table 4.1). The low organic carbon and nitrogen contents of the soil was possibly due to low inputs of organic amendments and high temperatures resulting in rapid organic carbon decomposition indicating the need for application of organic and inorganic fertilizers to enhance productivity. The general fertility status of the soil at the study area was low confirming the assertion that the fertility status of most Ghanaian soils are low (Adu, 1992).

5.2 Characterization of poultry manure

The poultry manure used was analysed to determine its nutrient composition. The C: N, C: P, Polyphenol: N ratios and, N and P contents are important parameters indicating the quality of organic materials. The mean C: N ratio of the poultry manure was 20.81 (Table 4.2) suggesting favourable N mineralization. Palm *et al*. (1997) pointed out that N mineralization takes place almost spontaneously after application of organic materials with C: N ratio less than 25. Nitrogen immobilization will occur if the C: N ratio exceeds 30 (Faassen and Dijk, 1987). The recorded C: P ratio (49.76) of the poultry manure used (Table 4.2) is also indicative of high quality. According to White and Ayoub (1983), a high quality organic material should have a C: P ratio less than 300. Results revealed low polyphenol: N ratio indicating a potential quick decomposition of the poultry manure amendment on the field. The mean N concentration in the PM was > 2.0 %. Palm and Sanchez (1991) established that organic soil amendments with N content between 2.0 - 2.5 % will enhance mineralization below which net N immobilization from the soil will be expected when applied. Phosphorus immobilization was not expected since P content of the manure was greater than the critical value of 0.25 % (Blair and Boland, 1978). Generally K, Ca and Mg contents of the manure were low (SRI, 2007).

5.3 Effects of poultry manure amendment and soil compaction on mineral nitrogen

5.3.1 Soil nitrate – nitrogen

Application of PM to the soil generally influenced soil nitrate - nitrogen levels. Levels of soil nitrate –N increased with the application of poultry manure (Tables 4.3a and 4.4b). The increase may be due to the high N content of the PM applied, its quantity and the lower mean C: N ratio (20.81) which resulted in mineralization after PM application. Palm *et al*. (1997) suggested that net mineralization of N in organic materials usually takes place with C: N ratios < 25. The increase in NO_3^- -N with the application of PM in this study corroborates with the work of Whalen *et al*. (2001) who reported that PM application increases the potential mineralizable N in the soil.

NO_3^- -N levels increased from 21 to 42 DAA and declined at 63 DAA. This is in contrast with earlier report by Logah (2009) who observed gradual increase in the levels of NO_3^- -N over time (from 21 to 84 DAA) in the minor season. The decrease in NO_3^- -N levels at 63 DAA in both experiments could be due to uptake by plant and losses from denitrification, leaching and volatilization.

Among all soil microorganisms, soil bacteria and fungi are the essential microbes that live on soil organic matter and play roles in the decomposition of organic residues

(Marinari *et al*., 2006). Compacted soils influence the habitat of these microbes by reducing pore size and altering soil physical properties characterized by reduced aeration and decreased water infiltration (Pupin *et al*., 2009). Under reduced aeration and prolonged saturated conditions, oxygen is reduced and microorganisms use nitrate instead of oxygen leading to denitrification. In this study (Tables 4.3a and 4.3b), the increase in soil compaction from 1.3 to 1.7 and/or 1.9 Mg m^{-3} generally resulted in a significant decrease in NO_3^- -N among treatments especially at 63 DAA. The decrease in NO_3^- -N may be due to the reduced aeration which resulted in denitrification. However, the compensatory effect of the manure was observed when higher rate of 6 t ha^{-1} was applied under high levels of compaction. For example, NO_3^- -N under lower levels of bulk density were expected to be significantly higher than that under high level of bulk density but due to the addition of high levels of poultry manure at high bulk densities, NO_3^- -N values were statistically similar in both cases.

It has been documented that increased supply of nutrients to plant in the soil occurs as soil microbial biomass increases and hence, nutrient dynamics is greatly controlled by soil microorganisms (Marinari *et al*., 2006). From the study, soil MBN correlated positively with NO_3^- -N and NH_4^+ -N in both experiments (Table 4.4c).

5.3.2 Soil ammonium – nitrogen

Soil ammonium –N followed similar trends as soil nitrate –N. Soil NH_4^+ -N levels generally increased with increase in levels of PM applied (Tables 4.3c and 4.3d). The accumulation of NH_4^+ -N in amended plots was due to the addition of PM which released NH_4^+ -N following mineralization of organic nitrogen. Under the levels of amendment, compaction and their interactions, NH_4^+ -N in the field experiment increased from 21 to 42 DAA and declined at 63 DAA. However, NH_4^+ -N levels in the pot experiment did not show any considerable increase at 42 DAA but decreased at 63 DAA (Table 4.3d). This decline in NH_4^+ -N could be due to crop nutrient uptake and losses through denitrification. Logah (2009) recorded similar trends of NH_4^+ -N levels in the soil over time and associated it to microbial activities and crop influence on nutrient uptake at different stages of growth.

From this study, it was observed that recorded nitrate –N values were generally higher than that of ammonium –N levels in both experiments (Tables 4.3a - 4.3d) and as such the total N mineralized from the PM was dominated by nitrate -N. This is so because under most soil conditions, NO_3^- -N is considered the most dominant form of soil N (Fageria and Baligar, 2005). This higher concentration of nitrate –N over ammonium –N does not necessarily indicate low ammonification, but can be as a result of quicker nitrification or immobilization (Quemada and Cabrera, 1995). However, it has implication for nitrogen loss from the soil system since N stored in the form of NO_3^- -N is subject to more leaching losses than N stored as NH_4^+.

5.3.3 Soil ammonium - nitrogen to nitrate - nitrogen ratio

Studying the dynamics of the two forms of absorbable nitrogen (NH_4^+ and NO_3^- -N) in the soil gives a better understanding of their effect on growth of maize crop. According to Yao *et al*. (2011), high rates of NH_4^+ in the soil normally results in toxicity and further leads to yield reduction. Generally, the various levels of compaction and amendments did not significantly influence ($P > 0.05$) NH_4^+ -N: NO_3^- -N ratios (Tables 4.3e and 4.3f). However, a decreasing trend from 21 to 42 DAA was observed in the pot experiment. At 42 DAA, the ratio of NH_4^+ -N: NO_3^- -N as influenced by PM ranged from 0.60 – 0.70 (Table 4.3e) and 0.39 – 0.40 (Table 4.3f) for field and pot experiments respectively. These ratios are slightly above the optimum value of 0.33 suggested by Adriaanse and Human (1991) though the dominant form of inorganic N in the experimental soil was NO_3^- -N.

5.4 Impact of poultry manure amendment and soil compaction on microbial biomass carbon and nitrogen

The presence of organic matter in the soil is considered an essential element of soil quality and productivity but determination of the biological active fractions of organic matter, such as microbial biomass carbon (MBC) and nitrogen (MBN) gives a good reflection about alterations in soil quality that influence nutrient dynamics (Kara and Bolat, 2009). Tetteh (2004) reported that MB is regarded as a very good indicator of soil fertility compared to the total soil organic matter.

Plots amended with PM led to higher levels of MBC which were significantly different from that of the control plots (Tables 4.4a and 4.4b). The higher MBC in PM amended plots may be due to an increase in microbial populations and activity. The MBC values recorded in this current study fall within the range of 40 – 2000 mg kg^{-1} as reported by Kaschuk *et al*. (2010) and Lu *et al*. (2013) for various forest, grassland and agricultural soils. Soil MBN followed similar trends as MBC. Plots amended with PM produced significantly higher MBN than that of the control plots. In their study, Agbenin and Goladi (1997) indicated that application of manure increased soil MBN.

Several authors have reported that increased soil compaction decreased soil microbial activity and biomass (Torbert and Wood, 1992; Li *et al.*, 2003). MBC and MBN were significantly influenced by the interactive effect of soil compaction and amendment at 42 DAA in both experiments (Tables`4.4a and 4.4b). Reduced levels of MBC and MBN with soil compaction were observed in both poultry manure amended and non-amended plots. However, the effect of soil compaction was more pronounced in the non-amended plots. The observation may be due to the fact that increase in soil bulk density in both amended and non-amended plots altered pore size distribution with its associated reduction in soil macropores and aeration inhibiting the growth of aerobic microbes (Pupin *et al*., 2009). This observation contrasts the findings of Shestak and Busse (2005) that soil compaction did not have any significant effect on soil microbial biomass carbon. According to the authors, the altered pore size distribution may be beneficial to the microbial community by increasing the volume of habitable pores while providing protection from larger predators.

The correlation analysis carried out revealed a strong positive strong relationship between microbial biomass C and organic carbon (Table 4.4c) in field and pot experiments indicating that soil MB content depended on the concentration of organic matter in the soil.

5.5 Impact of soil compaction on porosity and saturated hydraulic conductivity

Hydraulic conductivity decreased under increasing levels of soil compaction. Hydraulic conductivity decreased by 50.00, 62.50 and 75.00 % as soil bulk density increased from 1.3 Mg m^{-3} to 1.5, 1.7 and 1.9 Mg m^{-3} respectively. The reduction in hydraulic conductivity due to soil compaction could lead to drastic reduced water flow through the soil. It has been widely documented that water plays vital roles in the growth and development of plants including important soil processes such as nutrient transport and biological processes (Dec *et al*., 2008). Reduced water availability and uptake by roots will lead to poor root growth and development as well as final crop grain yield.

As hydraulic conductivity decreased under increasing levels of soil compaction, so also did total porosity. The results indicated that total porosity decreased by 15.70, 29.40 and 45.10 % from soil bulk density 1.3 Mg m^{-3} to 1.5, 1.7 and 1.9 Mg m^{-3} respectively. Reduced total porosity of the soil results in fewer macropores which affects air, water and nutrients uptake at adequate rate (Grzesiak, 2009).

5.6 Influence of poultry manure amendment and soil compaction on soil properties at harvest

Plots amended with PM increased the pH of the soil from the initial moderately acidic to slightly acidic level in both field and pot experiments at the end of the study. This corroborates with the findings of Lagomarsino *et al.* (2008). In their study, they reported that after four years of adding organic amendments, soil pH was influenced significantly. The control plots recorded the least pH values at the end of the experiment due to no addition of organic matter to the soil from PM which helps to improve soil pH.

The soil total N content at the experimental site before the study ranged from 0.12 to 0.14 % (medium). The final analysis however, revealed that total N content of the soil increased after harvest and varied from 0.13 to 0.22 %. However, there were no significant differences in N content in both amended and unamended plots and this could be attributed to the relatively short duration of the experiment. This is in accordance with the work of Moore and Edwards (2005) who did not observed significant changes in soil chemical properties in a short term but rather in a long - term study.

Plots amended with poultry manure at 4 and 6 t/ ha increased organic carbon over that of the control plots. However, organic carbon content in the amended plots showed no appreciable increase than that of the initial value (1.36 % - medium). This may be due to low characteristic nature of the fertility status at the study site coupled with high temperatures resulting in rapid organic carbon decomposition. This attest to the findings of Logah (2009) who reported similar trends of soil organic carbon content over time and associated it to high temperatures, low inherent soil fertility and aeration enhancing quicker decomposition by the action of microbes.

The results (Tables 4.6c and 4.6d) indicated that application of poultry manure decreased soil bulk density. Bulk density with respect to amended plots were generally lower than that of the unamended plots in the field experiment. Other authors reported similar findings on the effect of poultry manure amendment on soil bulk density (Felton and Ali, 1992; Shirani *et al*., 2002).The reduction in soil bulk density is attributed to the fact that PM is lighter as compared to soil particles and therefore its addition reduced the mass of the soil in a given volume and hence the reduction in soil bulk density. These results indicate the compensatory capabilities of PM in the reduction of soil bulk density.

5.7 Effect of poultry manure amendment, soil compaction and their interaction on N uptake of maize

Nitrogen uptake is the concentration of N in plant parts measured multiplied by the grain yield or dry matter produced expressed in uptake units (Sobkowicz and Śniady, 2004). The highest N uptake was observed in plots amended with poultry manure (Tables 4.7a and 4.7b). This shows the importance of PM application as it contains essential plant nutrients for the growth of plants. In both experiments, N uptake decreased from V12 to R6 (Tables 4.7a and 4.7b). However, N uptake in the ear was greater than that of the stover at R6 in both experiments. This increase in N uptake by the ear was due to the fact that it is a strong sink of high metabolic activities which caused retranslocation of nutrients from other portions of the plant to the grain. Yoshida (1981) reported that about 70 % of absorbed N by straw is retranslocated to the grain during ripening. According to Plenet and Lemaire (1999), retranslocation of N to the ears from leaves and stem predominates as the plant ages.

Higher N uptake was observed under field conditions than in the pot experiment. This could be due to greater interception of sunlight under field conditions for the production of photosynthates and greater exploitation of the soil volume by maize roots for the uptake of nutrients. Significant differences observed for N uptake in compacted plots may also be attributed to restricted root length into deeper layers to absorb moisture and nitrogen; hence the increase in bulk density resulted in reduced root growth limiting N uptake.

Correlation analysis between maize grain yield and N uptake indicated a strong relationship (r = 0.99 and 0.98) (Tables 4.10c and 4.10d respectively). It was evident that higher uptake of N by the crop contributed towards increased grain yield, which was not observable in the unamended treatment.

Nitrogen uptake in maize generally decreased as soil bulk density increased (Tables 4.7a and 4.7b). In Table 4.7a, N uptake in ear decreased by 8.76 % as bulk density increased from 1.3 to 1.5 Mg m^{-3} and to 12.73 % as soil bulk density increased further to 1.7 Mg m^{-3}. The decrease in N uptake of maize as soil compaction increased may be due to impeded root growth which limited the exploring ability of the roots in the soil medium and hence less N uptake.

5.8 Plant height and stover dry weight as affected by compaction and poultry manure amendment

The productive potential of plants in terms of grain yield is directly linked with important growth characters including plant height (Omotosho and Shittu, 2007). Results (Tables 4.8a and 4.8b) indicated that the different levels of poultry manure applied had significant influence on maize plant height. Plants on amended plots were significantly taller than those on the control plots due to the availability of nutrients from the poultry manure during the growing season. According to John *et al*. (2004), PM contains essential nutrient elements which is associated with high photosynthetic activities and can enhance roots and vegetative growth.

Maize plant height decreased as soil compaction levels increased. Plant height was greater at 1.3 Mg m^{-3} than at bulk densities of 1.5, 1.7 and 1.9 Mg m^{-3}. This significant retardation in plant growth may be attributed to mechanical impedance of the root in the soil. This attests to the work of Gediga (1991) that subsurface compaction of the soil significantly reduced plant height due to restrictive roots.

Biomass yield of corn generally increased significantly under both field and pot experiments with the increase in the application rate of PM at V12 and R6 (Tables 4.8c and 4.8d). Dauda *et al.* (2005) in their work, concluded that increase in the amount of PM applied resulted in an increase in vegetative growth of plants. From Tables 4.8c and 4.8d, amended plots produced significantly higher biomass than that of the control. This was due to the nutritional composition of the PM especially nitrogen which was converted into greater vegetative growth of the plant. Nitrogen is a component of chlorophyll and if available, chlorophyll formation will be enhanced leading to increased biomass. However, biomass production was reduced significantly as soil compaction increased (Tables 4.8c and 4.8d).

5.9 Grain yield and 100 seed weight of maize

Under the two conditions of study, PM application rates at 4 and 6 t ha^{-1} recorded significantly higher yields than that of the control (0 t ha^{-1}) showing the importance of PM application to the soil for the growth of maize. Ayoola (2006) reported that yields of crops were usually least in unfertilized/control plots because of the limited nutrients that the soil could supply without any external inputs which the crop had to use. It is observed from Tables 4.9a and 4.9b that PM application rate of 4 t ha^{-1} was more effective in producing grain yield compared to 6 t ha^{-1} due to luxurious consumption in the case of the latter (Tables 4.7a and 4.7b). These results corroborates with the findings of Boateng *et al*. (2007) that yields (biomass and grain) increased linearly up to 4 t ha^{-1} level of PM application and that higher applications to 6 and 8 t PM ha^{-1} continued to increase maize yields at a reduced rate; a probable case of diminishing returns. Haruna (2011) also observed similar trends that by increasing the rate of manure from 5 to 10 and 15 t ha^{-1}, there was a resultant significant depression in grain yield.

Soil compaction greatly influenced the grain yield of maize. The grain yield decreased as soil compaction increased from 1.3 to 1.5, 1.7 and 1.9 Mg m^{-3} (Tables 4.9a and 4.b). This reduction in grain yield may be attributed to poor root growth and development due to mechanical impedance by the soil and as such reduced nutrient uptake as soil compaction increased from 1.3 to 1.9 Mg m^{-3}.

With regard to amendment x compaction interaction, significant differences were observed among treatment means with each 0.2 Mg m^{-3} rise in bulk density resulting in a decrease in grain yield in both amended and non-amended plots. However, grain yield increased considerably in compacted plots amended with poultry manure at the rate of 4 and 6 t ha^{-1} relative to the control. This was due to the compensatory effect of poultry manure amendment on soil physical properties and the supply of essential nutrients. This confirms earlier report by Shirani *et al.* (2002) that applied PM on compacted soils significantly improved grain yield than yields on unamended compacted soils.

Increasing the levels of PM from 0 to 4 t ha^{-1} increased 100 seed weight from 14.44 to 19.90 g (Table 4.9a). This confirms the findings of Law-ogbomo and Remison (2009) that application of PM significantly increased seed weight of maize. Hundred seed weight declined as soil bulk density increased from 1.3 to 1.5, 1.7 and 1.9 Mg m^{-3} indicating the adverse effect of soil compaction on crop performance.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and conclusion

In the field and pot experiments, application of PM and imposition of different levels of soil compaction generally influenced soil mineral N levels, N uptake, microbial biomass carbon and nitrogen, plant height, biomass dry weight, grain yield and hundred seed weight. Application of poultry manure amendment positively affected crop growth through changes in soil N status in compacted soils. The increase in soil bulk density beyond 1.5 Mg m^{-3} significantly reduced plant and soil parameters measured in both field and pot experiments.

Mineral nitrogen (NO_3^- -N and NH_4^+ -N) increased from 21 to 42 DAA and declined at 63 DAA. Mineral N decreased with each 0.2 Mg m^{-3} increase in bulk density, however, addition of manure enhanced the levels by promoting favourable condition for soil microorganisms. Levels of NO_3^- -N were greater than that of NH_4^+ -N. However, this has implication for nitrogen loss from the soil system since N stored in NO_3^- form is subject to more leaching losses than nitrogen stored as NH_4^+.

Application of 6 t ha^{-1} PM generally led to the highest N uptake at vegetative (V12 or tasselling stage) and physiological maturity (R6) growth stages by altering the soil physical properties and improving the N status of the soil. The increase in soil compaction decreased N uptake, however, the application of PM in compacted soils registered an increase in N uptake which was comparable to the amended uncompacted plots and significantly greater than the unamended plots. Nitrogen contents in maize parts generally increased in the order of $0 < 4 < 6$ t ha^{-1}.

Application of PM significantly increased maize biomass and grain yields over the control plots in both experiments. The highest grain yield was 3004 kg ha^{-1} and 2453 kg ha^{-1} respectively in field and pot experiments. The interactive effect of 6 t ha^{-1} poultry manure and soil bulk density of 1.3 Mg m^{-3} (P_6Bd_1) produced the highest output among plant parameters measured. Addition of poultry manure at a higher rate (6 t ha^{-1}) decreased bulk density. Soil compaction significantly influenced all maize growth and yield parameters measured. The PM influenced the physico-chemical properties of the soil at the end of the study period. Soil pH, and available P contents of the soil increased over the initial values. Poultry manure generally helped reduce the adverse effects associated with soil compaction.

The application of PM generally influenced MBC and MBN in both field and pot experiments at 42 DAA. The interactive effect of bulk density and amendment significantly influenced ($P < 0.05$) MBC and MBN contents of the soil such that the highest MBN was recorded under 4 t ha^{-1} poultry manure in soil with bulk density of 1.3 Mg m^{-3} (P_4Bd_1) and the highest MBN was recorded in soils of bulk density of 1.3 Mg m^{-3} amended with 6 t ha^{-1} poultry manure (P_6Bd_1).

6.2 Recommendations

For maize production, application of 4 t ha^{-1} poultry manure in a 1.3 – 1.5 Mg m^{-3} soil bulk density is required for increased yields. However, the application of poultry manure at a higher rate will compensate the negative effects of highly compacted soils by influencing nitrogen mineralization, its availability and uptake for the growth of maize crop.

Prospective studies should consider the impact of application rate, timing and methods of application of poultry manure on compacted soils and the implication for nutrient uptake and crop yield. Multi-locational research is also required to confirm research findings reported herein.

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APPENDICES

Appendix 1: Calculated quantities of poultry manure applied on amended plots during the study

Plot area = 4 m x 3 m

= 12 m^2

If 10,000 m^2 = 1 ha

Then 12 m^2 = 0.0012 ha

Recommended rate of poultry manure is 4 tons/ha = 4000 kg ha^{-1}

4000 kg PM = 1 ha

? kg PM = 0.0012 ha

Hence 0.0012 ha required 4.8 kg PM

Based on the planting distance (80 cm x 40 cm), the total number of plant stands per plot was be 40 stands (hill)

= $\frac{4.8}{40}$ kg PM

= 0.12 kg PM

= 120 g PM per hill

Therefore, 120 g per hill was applied for the application rate of 4 t ha^{-1}

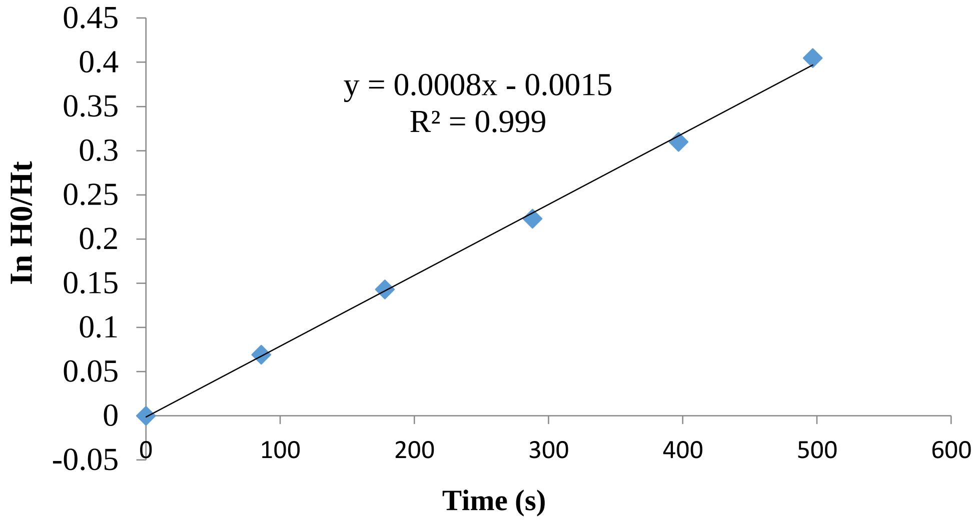
If 4 tons/ha = 120 g PM per plant,

Then 6 tons/ha = $\frac{6}{4} \times 120$

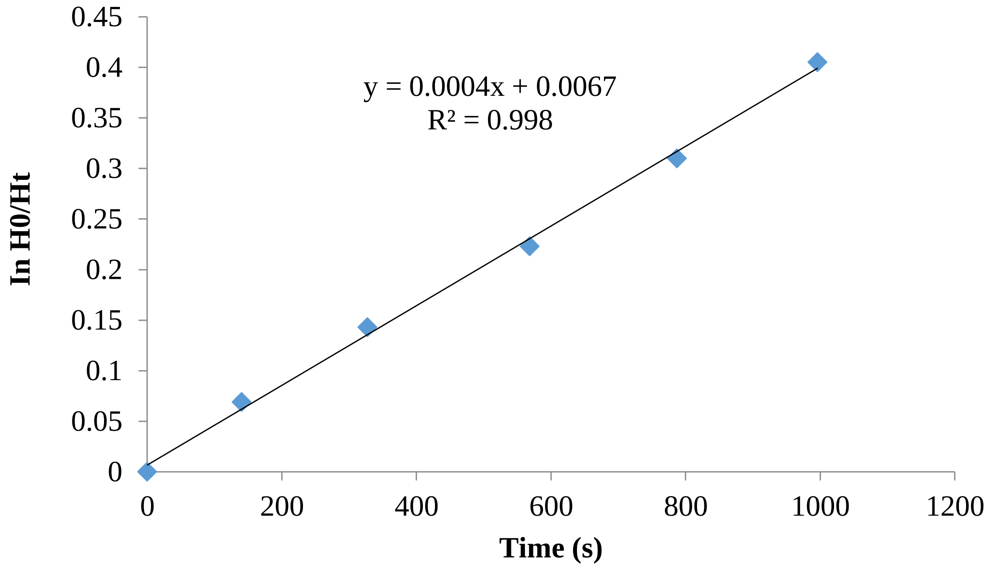
= 180 g PM per plant

Therefore, 180 g per hill was applied for the application rate of 6 t ha^{-1}

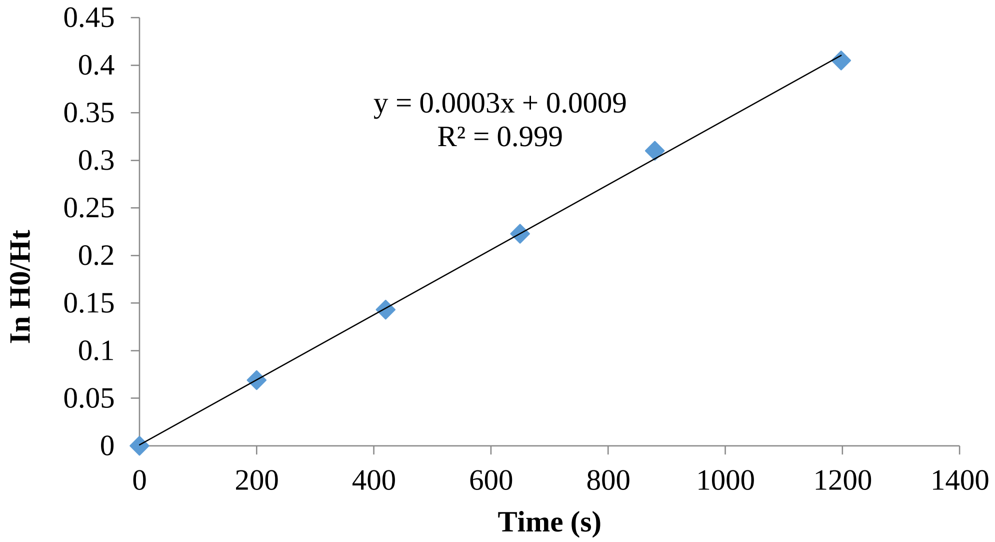
Appendix 2: Impact of soil compaction on saturated hydraulic conductivity



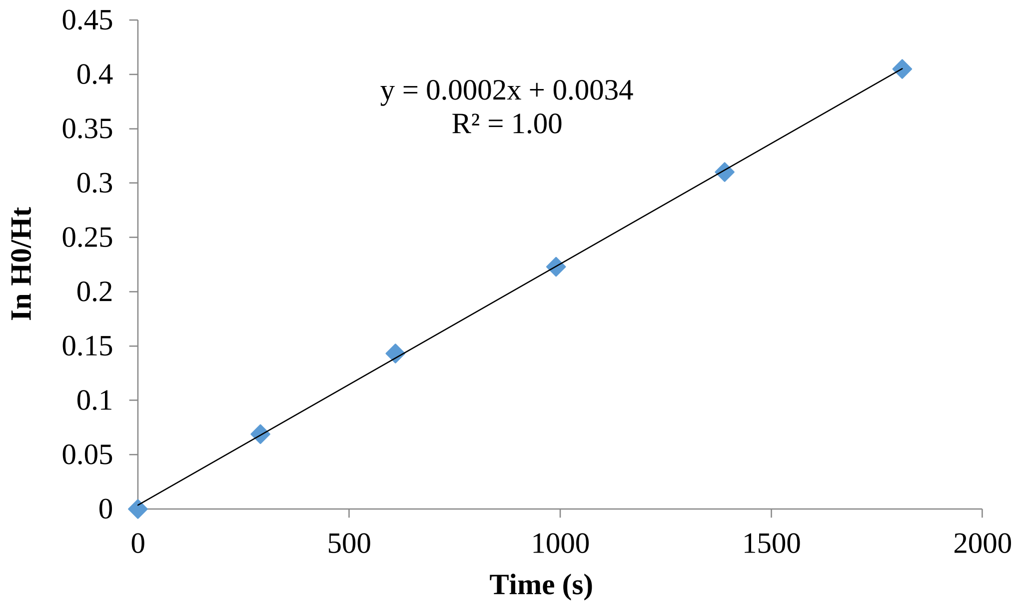
Appendix 2a: Coefficient of determination of hydraulic conductivity for soil bulk density of 1.3 Mg m^{-3}



Appendix 2b: Coefficient of determination of hydraulic conductivity for soil bulk density of 1.5 Mg m^{-3}



Appendix 2c: Coefficient of determination of hydraulic conductivity for soil bulk density of 1.7 Mg m^{-3}



Appendix 2d: Coefficient of determination of hydraulic conductivity for soil bulk density of 1.9 Mg m^{-3}

Appendix 3: Ratings of soil chemical parameters

Soil Parameter	Rating
Soil pH	
< 5.0	Very Acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Phosphorus, P (mg kg^{-1}) – Bray's No. 1	
< 10	Low
10 – 20	Moderate
> 20	High
Calcium, Ca ($cmol_{(+)}kg^{-1}$)	
< 5	Low
5 – 10	Moderate
> 10	High
Exchangeable Potassium ($cmol_{(+)}kg^{-1}$)	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High
ECEC ($cmol_{(+)}kg^{-1}$)	
< 10	Low
10 – 20	Moderate
> 20	High

Source: Soil Research Institute (2007)

Organic Carbon Content Walkley – Black method (% of soil by weight)	Rating
> 5.0	Very high
2.0 – 5.0	High
1.0 – 2.0	Medium
0.3 – 1.0	Low
< 0.3	Very low

Source: Boerma *et al*. (1995)

Appendix 4: Climatic data at the experimental site

Mean monthly weather data at Anwomaso during the course of the study.

Month	Temperature (^{0}C)		Relative humidity	Total monthly rainfall
	Min	Max	(%)	(mm)
Sept	22.20	30.63	88.00	189.10
Oct	22.20	30.89	85.81	221.30
Nov	22.53	31.78	85.07	43.60
Dec	21.47	31.51	74.22	13.90

Source: KNUST weather station

Appendix 5: Hand roller used in the compaction of treatments plots (Anwomaso)