UNIVERSITY OF EDUCATION, WINNEBA

ASSESSING THE USE OF TERMITE MOUND MATERIAL AS MEDIUM FOR GROWING COWPEA (*Vigna unguiculata* (L) Walp)

EUNICE OWUSU-AFRIYIE

MASTER OF PHILOSOPHY

(SOIL SCIENCE)

2022

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EUNICE OWUSU-AFRIYIE

(8172060002)

A Thesis in the Department of Crop and Soil Sciences Education, Faculty of Agriculture Education submitted to the School of Graduate Studies in partial fulfilment of the requirements for the award of Master of Philosophy in Soil Science in the University of Education, Winneba

2022

DECLARATION

I Eunice Owusu-Afriyie declare that with the exception of quotations and references contained in published works which have all been identified and acknowledged, this dissertation is entirely my own work and it has not been submitted either in part or whole for another degree elsewhere.

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EUNICE OWUSU-AFRIYIE **DATE**

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of this dissertation was supervised in accordance with the guidelines for supervision of thesis as laid down by the University.

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MR. E. K. ASIEDU **DATE**

(MAIN SUPERVISOR)

…………………………………. …………………………

PROF. KOFI AGYARKO **DATE**

(CO-SUPERVISOR)

DEDICATION

This work is dedicated to Samuel Osei Sarpong, my husband, Mr Emmanuel Kwasi Asiedu and Prof. Kofi Agyarko my supervisors for their support and encouragements

ACKNOWLEDGEMENT

My greatest appreciation and gratitude go to God, my supervisor Mr. E. K Asiedu of the College of Agriculture Education, University of Education, Winneba who supervised this work and offered valuable criticisms, corrections and suggestions, despite his tight schedule to enable me complete this work. I am also indebted to Prof. Kofi Agyarko, Elder Ben, Asmah all of College of Agriculture Education, University of Education, Winneba for their suggestions and help in terms of equipment and technical support. To my several friends including Collins, Achuliba, Hawa, Gyan, Mallam and those whose names I cannot mention due to space. I am grateful for your support, pieces of advice and encouragement.

Finally, I thank my family, Mr & Mrs Sarpong of Mampong for their support throughout this work. God bless you all.

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LIST OF ABBREVIATIONS

ANOVA	–	Analysis of Variance
CEC	–	Cation Exchange Capacity
C/N	–	Carbon/Nitrogen
E. C. E. C.	–	Effective Cation Exchange Capacity
EDTA	–	Ethylenediamine Tetraacetic Acid
FAO	–	Food and Agriculture Organization
GMT	–	Greenwich Mean Time
ISFM	–	Integrated Soil Fertility Management
LSD	–	Least Significant Difference
SOC	–	Soil Organic Carbon
T. E. B	–	Total Exchangeable Bases
UNESCO	–	United Nations Educational, Scientific and Cultural Organization
WAP	–	Weeks After Planting

ABSTRACT

A pot experiment was conducted at the University of Education, Winneba, Mampong - Ashanti campus now Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development to assess the use of termite mound material as a medium for crop production. Three soil types namely top, sub and termite mound soils were considered as the treatments for the study. These soil types were collected in 2018 and 2019 from the multi-purpose nursery of the college of Agriculture. Soil physical, hydrological and chemical characteristics, and growth and yield of cowpea were determined in both major and minor seasons. Soil nutrients such as N, P and K, organic matter and pH values were higher in the top soil. SOC in top soil was 45 and 105 % more than the termite mound and sub soils respectively in the major season. The top soil again recorded total N which was about 33 and 122 % more than the termite mound and sub soils, respectively. TEB, ECEC and base saturation were higher in the top and termite mound soils than in the sub soil, while exchangeable acidity was higher in the sub soil than the top and termite mound soils. Similarly, soil physical and hydrological characteristic such as bulk density, moisture and porosity were favourable for crop production in the top soil. In both seasons, the top soil improved the growth and yield of cowpea better as compared to the sub soil, and the termite mound soil. In the major season, the top soil recorded a total grain yield of 390.0 kg/ha which was about 16 and 62 % more than the amount produced in the termite mound soil and the sub soil respectively. Total grain yield of cowpea correlated positively with organic matter, total N, available P, exchangeable K, ECEC and pH (r= 0.725, 0.793, 0.686, 0.749, 0.646 and 0.740 respectively).

The order of preference for crop production should be top soil > termite mound soil > sub soil.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Soil fertility is one major biophysical constraint to crop production in sub-Saharan Africa and is linked with numerous degradation processes which further degenerate into other spiral productivity and environmental quality issues (Ajayi, 2007; Tulley *et al*., 2015). Naturally, African soils are formed from deeply leached parent materials which cause them to have low nutrients and are not able to sustain crops over long periods without nutrient replenishment (Tully *et al*., 2015).

Studies of Gadermiere *et al.* (2020), show that effects of tillage and inadequate application of nutrients and organic matter cause a decline in organic matter content of the soil. This positively affects retention of essential plant nutrients, the breakdown of soil physical structure and reduced water infiltration and storage capacity of the soil (Gadermiere *et al.*, 2020). Beyond this, most small-scale farmers face other degradation processes including erosion, salinization and acidification (Tully *et al.,* 2015). The decline of soil fertility is also dependent on physical and biological degradation of soils and agronomic practices. A positive relationship exists between poverty and land degradation, national policies and institutional failures (Vanlauwe *et al.,* 2015). Aside degradation, soil fertility is linked to other human, environmental and biological problems such as malnutrition and termite habitation. Several authors have reported on termite mounds use in soil fertility enhancement in Zimbabwe (Nyamapfene, 1986; Bellon *et al.,* 1999), Niger (Brouwer *et al*.,1993), Sierra Leone (Ettema, 1994), Zambia (Siame, 2005) and Uganda (Okwakol and Sekamatte, 2007). Nyamapfene (1986) and

Logan (1992) indicated that farmers either plant specific crops on termite mounds or spread soil from termite mounds in their fields. An example of agricultural production around termite mound is the chitemene system of agriculture cited in southwestern Tanzania (Mielke and Mielke, 1982). Malawi farmers have been reported to plant various crops that include bananas (*Musa* spp.) near termite mounds. In Uganda, the scenario is quite different as farmers plant onions (*Allium* spp.), tomatoes (*Solanum* spp.), pumpkins (*Cucurbita* spp.) and maize beside termite mounds (Okwakol and Sekamatte, 2007). In Zimbabwe, okra (*Abelmoschus esculentus*), pumpkins, sweet sorghum (*Sorghum* spp.), and late-season planted maize, that requires good water and nutrients supply, are cultivated practically on termite mounds (Nyamapfene, 1986). Brouwer *et al*. (1993) also indicated that in Niger, the smallholder farmers prefer to grow sorghum on termite mounds than the surrounding soils.

The technology used by some farmers is to break termite mound and then spread the soil in their field. For example, in southern Zambia, farmers remove portions of the termite mound and make sure that the base and colony are not destroyed. This soil is then taken to the field and mixed with the top soil before the rains begin. In areas where conservation farming is practised, soil from termite mounds is put in planting basins (Siame, 2005) and in ripped lines. In South Africa, some patches of excellent well-cared for sugarcane, known as "isiduli", are prominent characteristics of sugarcane fields grown on sandy soils. These correspond to some termite mounds normally evened by ploughing (Cadet *et al*., 2004). Similarly, in Zimbabwe, farmers are reported to utilize soil from termite mound to enhance soil fertility (Nyamapfene, 1986; Bellon *et al*., 1999).

Rooting medium is very important to crop production as it provides nutrients adequate for plant growth, allows for maximum root growth as well as mechanical support to the plant (Jaleta and Suleiman, 2019). Growing crops in the right medium results in quality fruits and improved yield (Jaleta and Suleiman, 2019). It is in view of this practice that some farmers collect termite mounds and deposit them where they intend growing crops (Lopez, 2001). It is believed to be rich in total phosphorus, nitrogen and organic carbon than the adjacent soil.

In spite of all the above, these mounds generally have zero vegetation implying its unsuitability for crop production. Research by White (2006) reveals that the decomposition of wood and other materials by the fungi in mounds is so efficient that the soil is hardly enriched in organic matter. Other studies on termite mounds reveal that termite mounds are difficult to work on due to their extreme hardiness. This goes a long way to affect water infiltration (Lavelle and Spain, 2001). A soil that has been occupied and engineered by termites, has its nutrient fluxes having the potential to extend beyond the lifetime of the colony (Chisanga *et al.*, 2020). Such long-term effects may contribute to the relatively low level of organic carbon recorded in many soils (Woomer *et al.,* 1994; Chisanga *et al.,* 2020). Jones (1990) proposed that significant proportions of carbon volatilization on some termite infested sites is due to the rapid and efficient turnover of litter by termites which causes the soil carbon pool to be by passed and reduces carbon build – up.

1.2 Problem Statement

Generally, trends of crops yield in most African countries is poor (Dilley *et al*. 2005; Sultan *et al.*, 2019). This challenge is mainly attributed to poor soil fertility (Tulley *et al.*, 2015). Activities of certain biological agents such as bacteria, fungi and termite parent materials impede soil productivity in Africa, thus leading to poor yields and low-income transcending into low standards of living (Tulley *et al.*, 2015). Again, termites are noted for denuding the soil and rendering it unproductive for vegetation and crop growth (Woomer *et al.*, 1994). Adequate studies on termite activities in crop fields had focused on the physical damage on crops (Garba *et al.*, 2011). However, no efforts were directed at land denudations (Garba *et al*., 2011). Termites cause physical damage to agricultural land by reducing suitable areas available for cropping through hundreds of galleries (mounds) establishment. These impact severely on economies of agricultural production through yield losses per hectare of land area of the crop fields (Vkaegbu and Akanigbo, 2004).

Successes in the use of termite mound soil as an amendment in crop production has been reported by several studies. Mavehangama and Mapanda (2012) studied the nutrient status of organic soil amendments from selected wards of Chivi District in Zimbabwe and found that use of organic amendments such as termite mound is a common practice in communal farmlands of Zimbabwe. The study observed that the differences in the nutrient supply potential of types of animal manure and various types of soil amendments that include termite mound soil have not been fully investigated (Mavehangama and Mapanda, 2012). This was similarly reported by a recent study of Enagbonma and Babalola (2019), where it was stated that there was less information on specific crop performances in relation to termite mound soils. Similarly, report of

Chisato (2013), indicates that termite mounds reduce vegetation cover and makes it difficult for crop growth. There is paucity of information on the use of termite mound soil for agricultural production in the whole Ghana. This study was therefore undertaken to evaluate the effect of termite mounds soils and ordinary soils (top and sub) on the growth and yield of cowpea in the savannah transitional zone of Ghana.

1.3 Justification

There is little or inadequate documentation and research to ascertain the use of termite mound soil as a source of nutrients for cowpea production despite convincing literature on the positive nutrient status of termite mound soils (Chisanga *et al.*, 2020). In view of this, there was a need to establish viable and environmentally sound optimum rates of termite mound soil application as part of the integrated soil fertility management (ISFM) component in sustainable agriculture. Specifically, in Ghana, little work has been done on the agricultural productivity of termite mound material and as such, the need for this research. The findings of this research will promote the commercial and domestic production of crop which will in turn help to provide jobs for people and also eliminate food scarcity. The government will also save resources on importation of food. The results of the study when adopted will enhance household income and reduce rural-urban migration.

1.4 Hypothesis

This study proposes that the use of ordinary top soil for crop production would result in better crop growth and yield compared to the termite mound material within the same area.

1.5 Research Objectives

The main objective of this study was to assess the agricultural benefit of the use of termite mound material as medium for crop production in Ghana.

1.5.1 Specific Objectives

i. To estimate the physicochemical properties of termite mound material relative to ordinary top soil and sub-soil.

ii. To determine the hydrological properties of termite mound material relative to surrounding top soil and sub soil.

iii. To evaluate the growth and yield of cowpea on surrounding topsoil vis a vis termite mound material and sub soil.

1.6 Significance of the study

Results of this study will help selecting termitaria in preference to the adjacent soil (0-10 cm) or vice versa, the belief that soil processed by animals is considered to be safer than that which is not processed will be well cleared; it would also help to advance argument that the inclusion of termite secretions in mounds could also be beneficial. This work will also contribute to literature as per termite mound and its agricultural importance and fill needed knowledge gaps.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Termites

Termites are a varied group of social insects living in nests or colonies, consisting of multiple generations, numerically ranging from several thousand to several million individuals at maturity, depending on the species, availability of food resources and soil environment (Khan and Ahmed, 2018). They are in the order Isoptera consisting of over 2600 species (Khan and Ahmed, 2018). Though termite classification and actual taxonomic position have not yet been concluded as it has recently been revised and the classification in the order Isoptera is now included as part of the order Blattaria (Matsui *et al*., 2009). However, for the sake of consistency with the many references and literature used, the order Isoptera will be used throughout the thesis.

In Australia, there are 350 termite species recorded and at least 90 undescribed species while 260 species have been described (Khan and Ahmed, 2018). Termites are usually found in terrestrial environments in the warmer regions of the world, mostly in the tropical, subtropical and temperate regions and rarely found at altitudes of more than 3000 m (FAO, 2020). Some of these termites solely depend on wood cellulose material for their food, either on living or dead trees, or the woody tissue of plants, intact or partly decayed (FAO, 2020). Each colony is composed of specialized groups, differing in behaviour and body shape, and showing a complex division of labour, each performing its own task within the colony; reproductive (king and queen, sole responsibility being egg production and distribution by colonizing flights), sterile workers, especially in many of the Termitidae (responsible for shelter tube construction, gathering of food and feeding the young and others), and soldiers (responsible for protecting the colony) (FAO, 2020). The order *Isoptera* is classified into seven families usually presented in their phylogenetic orders, from the most primitive to the advanced; these, include *Mastotermitidae, Hodotermitidae, Kalotermitidae, Termopsidae, Rhinotermitidae, Serritermitidae* and *Termitidae* (Engel *et al.,* 2009). Different categorizations and classifications of termites exist depending on individual or combined factors of feeding groups, nesting habits, etc. (Engel *et al.,* 2009). Based on their habits and moisture content requirements, termites can be divided into the following categories (Engel et al., 2009): i. Harvester termites are those which feed on plant litter and grass but not wood. ii. Damp wood termites are those which need considerable source of moisture to live and hence live-in old tree stumps, rotting logs and timber cladding and pieces of buried timber.

Although they are restricted in terms of their nesting and foraging activities, once established they can attack sound wood in the structure of buildings. iii. Dry wood termites live entirely above ground within dry wood and do not need a soil medium as they are entirely dependent on the wood for their source of moisture. They are major pests but compared to the other termite groups they live in small colonies and hence easier to control. iv. Subterranean termites are those considered economically important as they are wood feeders and attack and damage timber-in-service. They live in nests in the soil and in trees that have been first infected with decay fungi. They forage from their nests and attack timber-in-service by building shelter tubes composed of moisture, soil, saliva and their own excreta. Not only does this protect the soft bodied termites from desiccation, but also from predators, such as ants (Khan and Ahmed, 2018).

2.2 The role of termites in soil condition improvement

Termites dominate certain places like Australia and Chad, especially the semi-arid and arid regions (Khan and Ahmed, 2018). They play very vital roles in the ecological processes of such environments. They provide conducive environment for vegetation restoration by modifying some properties of the soil which in turn improve the nutrient cycling and ultimately its release (Fergnani, 2008). Although they also contribute to global warming due to their emission of greenhouse gases, methane and carbon dioxide (Gadermeiere *et al.,* 2020), through their feeding, nesting and burrowing activities, termites overwhelmingly regulate soil water properties, particularly water infiltration rates and storage (Leonard and Rajot, 2001). They contribute a great deal towards nutrient and carbon cycling, through the transformation, turnover and conservation of soil organic matter and nutrients as well as water (Garba *et al.,* 2011).

They increase crop production under a minimum tillage conventional farming system (Sultan *et al.,* 2019). In some other cases, benefits have been reaped from the use of soils from termite mounds as amendments to improve the physical condition of degraded soil. Application into a relatively small area of such materials collected from interspersed mounds found throughout farmlands and forest areas resulted in marked improvement in the water holding capacity of the soil (Suzuki *et al*., 2007). Several studies have reported the use of termites in soil rehabilitation or restoration processes of degraded soils. Laboratory experiments to investigate changes in soil quality of strip mine soils and degraded soil in humid forests (Donovan *et al*., 2001) showed beneficial changes after manipulation of the soil by termites. Mando *et al*., (1999) reported that the addition of termites and mulch into a degraded soil resulted in a better plant diversity, plant cover and biomass production in crusted Sahelian soils. Similar observations were also made in such soils in an Australian savannah (Dawes, 2010) and in sites in Brazil subjected to selective logging, and cleared for pastures and farming (Alves *et al*., 2011).

2.3 Termite symbiosis and impact on soil microbial activities

There is adequate documentation of termites and their symbionts and through this association termites play very important role in digestion and decomposition of organic matter as well as normalizing nutrient- dynamics or global cycling, through the ingestion and redistribution of minerals (Issoufou *et al.,* 2019). The breakdown of the woody plant components, i.e. cellulose and lignin, from plants and soil organic matter occurs in the lumen of termites (Hodson, 2019).

There are two groups of termites namely; functioning or feedings groups depending on their feed sources and subsequent effect on soil (Kumar, 2020). Some termites harbour a dense and diverse population of bacteria and cellulose digesting, flagellate protozoa in their alimentary tract on which they depend for their cellulose digestion (Butera *et al.,* 2016) They include the six families in the phylogenic order- namely, *Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae,* and *Serritermitidae* (Butera *et al.,* 2016). Termites feed on humus and build their nests with faecal matter mixed with coarse, inorganic soil particles. Several lower termites feed almost exclusively on wood which is decomposed by the interaction of organisms. Generally, wood is lower in nutrient content (especially nitrogen and phosphorus) than other plant materials, but the capacity to fix nitrogen overcomes this disadvantage for such decomposers. In these circumstances, the fresh input of nutrients by nitrogen fixation is very necessary ecologically. The second group, higher termites (family

Termitidae) or fungus-growing termites, are the largest family comprising three fourths of all termite species. They harbour a dense and diverse array of gut bacteria, but most typically lack protists and have a more elaborate external and internal anatomy and social organization than do the lower termites (O'Brien and Slaytor, 1982). Termites usually have microhabitats conducive for the development and sustenance of the symbiont microorganisms, with the provision of optimum security from predators and other interferences, minimum or no extreme fluctuations of wetting and drying cycles, as well as abundant and accessible nutrients (Veldus *et al.,* 2017). Therefore, termites significantly influence and regulate the structure of soil bacterial and fungal communities.

2.4 Termites in soil rehabilitation

Biological interference in maintaining soil productivity has been used as the only option in southern Brazil where most of the areas of natural grass land were developed on acid soils, with high levels of exchangeable aluminium (Mozzar, 2019). Plant revegetation is difficult in heavily contaminated mine dumps as a result of lack of nutrients in the thin soils and high level of metal and acid contaminants (Shepherd, 2019). Rehabilitating soils using termites to reinitiate or enhance the soil and water balance is one of several ways of reducing the effects of climate change or perhaps reverse its effect on the shifting trend of ecosystems (French and Ahmed, 2011). Mando *et al.,* (1999) observed that the addition of termites together with the addition of dry organic matter can accelerate the creation of the necessary conditions for plant development. However, witnessing such significant improvement depends on the climatic, ecological and management factors as well as preceding levels of soil compaction, physical and chemical degradation. In an experiment carried out in the Chihuahuan desert by Elkins *et al.,* (1986), the removal of subterranean termites resulted in the complete disappearance of a dominant perennial grass while instigating a chain of changes in the soil properties. In the same experiment, termite effects resulted in the decrease of the productivity of a dominant shrub in the system while changing the composition of a spring annual plant community. In dry tropical savannas, trees associated with termite colonies remained green throughout the year, due to the sustenance of water from the termite colonies lasting well into the dry season (Nkunika et al., 2013).

The ability of some termite species to survive under extreme conditions and high levels of disturbance effects initiating the recovery of soil function and productivity (Nkunika et al., 2013). Termites persevered more than earthworms to disturbances in soil caused by continuous crop production, when compared to the fallow in 12 long-term farms in Western Africa (Ayuke *et al.,* 2011). Indeed, it is understandable that the response of natural vegetation or crops to the improved water availability due to termite effects is a relevant field to explore when considering the effectiveness of soil and water management techniques (Ayuke *et al.,* 2011). The analysis of termite activities with respect to their role in the restoration of degraded ecosystems or mitigating effects of climate change and global warming as well as desertification becomes imperative if we are to maximize the ecological benefit, we get from them or at least adopt some of the complex mechanisms they use in their efficient micro-ecosystems. Therefore, this thesis examines research works which reflect on the current state of knowledge pertaining to termites (Isoptera) and their interaction with the soil.

2.5 Effect of termites on soil physical properties

Movements and functions of termites in the soil help to structurally, maintain the soil, provide food and water for the soil, as well as maintain the moisture and temperature of the soil (Cornelius and Osbrink, 2011). Below are brief descriptions of the impact of termite activities on selected soil physical properties- texture, structure, infiltration, run off and soil water storage.

2.5.1 Effect of termite activities on soil texture and structure

Soil texture describes the relative amounts of different soil size particles of sand, silt and clay in the soil. The continual transport, erosion and reconstruction of termite mounds and nests results in the redistribution of the soil particles, consequently loosening or disturbing the soil profile resulting in soil texture change which is more pronounced than the change in the chemical properties of the soil (Cornelius and Osbrink, 2011). The preferential use of finer soil particles to construct nests, mounds and feeding galleries results in higher content of finer soil particle size of the mound material, in fact as much as two to three folds (Cornelius and Osbrink, 2011). Termites use their saliva and other body wastes to cement soil particles together when constructing their mounds with preferably finer soil particle sizes. By choosing higher proportions of kaolinite with some chlorite and montmorillonite, the termites can ensure that the surface of the mounds is harder because the clay particles fill in between the sand grains (French and Ahmed, 2011). When compared to the mounds, however, the construction of feeding galleries and burrowing channels improves the soil porosity and water transmission characteristics in which the macropores would otherwise be significantly reduced or eliminated during the packing and remoulding process in the mounds (Nkunika et al., 2013).

2.5.2 Effect of termite activities on infiltration, runoff and soil water storage

The effect of termite activity on the soil hydrological characteristics has only been studied in relation to the individual components of the soil water balance. Thus, in some studies only soil water potential was surveyed as a resultant complex interaction between the different components of the soil water balance and one that greatly determines soil water availability for plants (Cornelius and Osbrink, 2011). A lot of void is created on surfaces of the soil by their excavation and construction of feeding channels as well as foraging holes, thereby significantly increasing infiltration by an average factor of two to three (Ahmed *et al.*, 2019).

Not only do they help increase infiltration rates but also help in intercepting the runoff water with the help of some roughness created on the surface (Ahmed *et al.*, 2019). Their interconnectivity also helps in the continuity of infiltration even after the soil surface has become saturated and thus increase water availability (Ahmed *et al.*, 2019). The relative compactness and the higher clay content of the termite mound increases its water holding capacity by decreasing its porosity, or increasing the proportion of micropores. The same structure, therefore, discharges as runoff most of the rainwater to the surrounding soil. It is also responsible for the shrinking/swelling capacity of the mounds which in dry areas, help increase the infiltration of water into the mound and its deep percolation. Infiltrated water is readily available to plants when it is stored in the micropores. As the water stored in the soil is related to the amount of water input by infiltration, termite modified soil structure and ultimately increased soil water stored (Ahmed *et al.*, 2019).

2.6 Role of mound building termites on modification of soil chemical properties

Chemical properties of soil are subjected to modification as termites influence cycling/redistribution of soil organic matter and nutrients in the ecosystem through collection and utilization/decomposition of food (e.g., wood, litter, humus etc.), excretion of organic matter as well as differential selection of soil particles, incorporation of saliva and/or excreta during mound building or incorporation of excreta in certain region of their nests (Orhue *et al.,* 2007).

Additionally, in the case of Macrotermitinae, termites use their excreta to construct fungus combs which are further utilized as food (Lelisa, 2016). The use of salivary secretions and faeces in building mounds and runways raises their organic matter content. Hence, soil organic matter content is usually higher in and near the termite mounds than in the soil unaffected by termites (Lima *et al*., 2018). However, soil organic matter content of the mounds of fungus growing termite species can be similar, higher or lower than the surrounding control soil, depending on the soil properties and the species concerned (Orhue *et al.,* 2007). The mounds of bigger termites are usually constructed from subsoil and remain lower in content of organic matter than the surrounding top soils (Orhue *et al.,* 2007). This concept is same for total nitrogen content, but not necessarily in equal proportions as carbon, therefore carbon/nitrogen (C/N) ratio of the mounds are also elevated as compared to the soil from which they are derived. Studies on various termite species across the world reveal that their activities especially incorporation of organic matter in the form of excreta/ saliva usually enhance the levels of phosphorus, exchangeable cations (potassium, calcium, magnesium) and cation exchange capacity compared with the adjacent undisturbed soil profiles (Lelisa 2016 and Lima *et al*., 2018). Sileshi *et al*. (2010) reported that mounds of

Ancistrotermes, Macrotermes, Odontotermes, Cubitermes and *Trinervitermes* are significantly enriched in clay (75%), carbon (16%), total nitrogen (42%), calcium (232%), potassium (306%) and magnesium (154%) compared to the surrounding savanna soil. Nagaraju *et al.* (2020) indicated that termites introduce significant chemical changes in the mound materials and rare earth elements based on the biological absorption coefficient of the mounds. Studies show that large termite mounds, ventilation system and location sites of the internal ventilation impeded drainage and resulted in the accumulation of calcium, phosphorus and other nutrients close to the base of the mound (Scarcenelli *et al*., 2009). It has also been observed that Macro termite mounds slightly have higher pH than the surrounding land top soils and subsoils. With increasing pH along a slope away from a termite mound, Scarcenelli *et al*. (2009) observed significant influence of land slope in a degraded grassland area of Brazil.

2.7 Comparing the characteristic of termite mound and adjacent soils

2.7.1 pH

There is generally little difference between soil and termite mounds in terms of pH. Calcium carbonate accumulation is the cause of the general increase in pH of Macromeres spp. mounds. Similarly, their decrease in other mounds is related to organic-rich excreta. Usually, the pH of the mounds ranges from 4.2 in mounds with, lower values: 4.2 ± 0. 7 in the nursery or carton material and 5.9-6.8 in soils (Okello-Oloya *et al*. 1985).

2.7.2 Organic carbon

There is generally higher organic carbon content in most termite mounds compared to adjacent soils (Issoufou *et al.,* 2019). This varies also within the specific mounds depending on where there is high activity of termites. Mostly, it generally increases from the outer mound to the innermost mound structures. For example, *Coptotermes acinaciformis* mounds have a mean of 2.8 ± 0.5 percent of organic carbon in the mound outer casing and 4.2 ± 3.4 percent in the nursery and the carton part (Issoufou *et al*., 2019).

2.7.3 Phosphorus

In general, mounds have a higher phosphorus content than adjacent soils. The average, dilute, acid-extractable phosphorus in termite mounds and soils studied in Australia are respectively: 18.5 mg/100g and 11.5 mg/100g. Coventry *et al*. (1988) reported values 2 to 3.7 times higher in the mounds. There are no consistent variations between mound levels although the lower part of the mound seems to have a lower content. Lee and Wood (1971) reported that the distribution of phosphorus in the mound is fairly uniform.

2.7.4 Potassium

As with calcium, potassium values in the termite mounds are generally higher than the soil from which they originate but may be only slightly higher or even lower than the topsoil values and do not seem to be closely linked to organic matter. As for calcium and magnesium they vary according to the species and the sample position. There are greater differences between the total and the exchangeable potassium than for calcium and magnesium. Okello-Oloya *et al*. (1985) reported total potassium values ranging from 20.0 -27.20 mg/100g for mounds and 13.0 – 35.20 mg/l00g for adjacent soils, while the exchangeable potassium varied from 5.5 - 32.8 mg/100g to 13.3 - 25 mg/100g for mounds and adjacent soils, respectively. There are no special patterns of exchangeable potassium associated with the different levels of mounds (upper, middle and lower).

2.7.5 Calcium

Most studies across the globe show a higher calcium content in termite mounds compared to surrounding or adjacent soils (Apori *et al.,* 2020). In some studies, there are reports of higher exchangeable calcium values than acid extractable or total calcium. For example, in Okello-Oloya *et al*. (1985), the total calcium values range from 4.4 ± 1.6 to 21.8 ± 6.8 mg/100g while the exchangeable calcium values range from 122 ±17.7 to 227 ± 54.3 mg/100g. The total calcium values were abnormally low compared with the acid-extractable values reported by Lee and Wood (197l). The procedure of extraction mentioned was a digestion with hot hydrofluoric acid. While no specific details of the method are available, it is likely that the fluorides would interfere with calcium extraction. The increase of calcium content within mounds seems to follow the increase of organic carbon content, although Lee and Wood (1971) observed no precise correlation between the two. Acid extractable calcium values in Australian mounds analysed by Lee and Wood (197l)" vary from <10 to 560 mg/100g with a mean of 173 ± 156 mg/l00g in the mounds and 60 ±5 6 mg/100g in the soils (0-10 em fraction or closest to this profile ex.: 0-7.5 em). The exchangeable calcium values follow the same kind of range. The values vary greatly with the location, species and the part of the mound analysed. For example, a Nasutitern1es triodiae mound was found to have 150 mg/100g exchangeable calcium in the nursery and only 4 mg/100g in the mound outer galleries. Generally, Okello-Oloya *et al* (1985) found in Amitermes spp. mounds that the exchangeable calcium is higher in the upper and middle level part of the mound than in the lower and the pediment section, but always higher than the surrounding soil.

2.7.6 Magnesium

Generally, the magnesium content of mounds is higher than that of the surrounding surface soils, as for other elements, it varies with the species responsible for the building, or the locations. Most of the magnesium reported in the literature is exchangeable magnesium. In Australia, total magnesium data have only been reported by Okello-Oloya *et al* (1985). Similar increases have been noted for Drepanotermes and Tumuliterme, *Lee and Wood* (1971) reported greater increase of exchangeable magnesium for some species. For example, a *Coptotermes acinaciformis* mound's outer casing contained 41.3 mg/l00g of exchangeable magnesium, while its adjacent soil had only 2.4 mg/l00g and a *Nasutitermes triodiae* mound had 83.9 mg/100g in its mound nursery compared with 3.6 mg/100g in the adjacent soil. An increase of magnesium of 4-5 times has been recorded in two mounds (traditionally used by Aboriginal people) compared to the surrounding soil. In Australia, the average total magnesium reported by Okello-Oloya *et al* (1985) for mounds of *Amitermes vitiosus* and *Amitermes laurensis* is 18.1 ± 7.2 mg/100g. This is comparatively low compared with the value they found for the exchangeable magnesium (24.1 ± 11.4 mg/100g). The reasons for this could possibly be explained in the same way as already mentioned for calcium. The distribution of exchangeable magnesium in mounds and soils varies between sites but seems to be consistently lower in the lower level of the mound.

2.7.7 Sodium

Like the other elements already mentioned, sodium content seems to be higher in the mound than in the surrounding soil, although Okello-Oloya *et al.* (1985) showed that at some sites the levels were much lower. Values vary greatly according to the procedures used, the species and the location. Okello-Oloya *et al.* (1985) reported total sodium values ranging from 7.0 ± 3.0 to 23.0 ± 9.0 mg/100g in mounds and 9.0 ± 5.0 to 18 ± 26 mg/100g in the soil, compared with the exchangeable values of 0.9 ± 0.5 to 2.3 ± 1.8 mg/100g in the mounds and 0.5 ± 0.1 to 5.3 ± 6.9 mg/100g in adjacent soils.

2.7.8 Iron and Aluminium

The iron and aluminium content of termite mounds has been poorly studied around the world. Stoops (1964) reported an increase of free iron in *Cubitermes* mounds. In Australia, Okello-Oloya *et al.* (1985) reported values for iron and aluminium respectively of 1.4 and 3.6 % for mounds and 1.1 and 3.1 % in the soils. This indicates a slight increase of those values in the mound compared with the soil. The variations of iron between sites were also very slight.

2.7.9 Manganese and Zinc

Very little has been reported on these elements. Dhembare and Pokale (2013) in Venezuela reported higher concentrations of manganese in the mound of Nasutitermes sp. than in the nearby soil, while the zinc levels were lower. Okello-Oloya *et al.* (1985) reported manganese values of 26.4 mg/100g in the mound and 24.7 mg/100g in the soil, while Coventry *et al.* (1988) reported anomalous concentrations of zinc in termite mounds compared with the surrounding soil. There has been no data reported on cobalt.

2.8 Agricultural importance of termitaria

Termite mound used as a soil amendment has been discussed by many authors. The results are often divergent and depend on the properties of the crops, the soils and the habits of different species of termites. In deficient soils, termitaria can provide nutrients. Sheppe (1968) observed that when the subsoil is richer than the topsoil, the termitaria are used in preference to the adjacent soils by African natives to plant their crops. In many parts of Africa and Asia, better crops such as vegetables, sisal, sorghum, maize, cotton and tobacco have been obtained on termite mounds or fields where the termite mounds have been levelled. In Thailand, Pendleton (1971) reported that the farmer use mounds for growing cotton, vegetables and tobacco but that the productivity of the levelled termite mound is very irregular. In Australia, Okello-Oloya and Spain (1985) have reported an increase of biomass of *Digitaria ciliris* (an annual grass) and *Stylosanthes hamata* (a pasture legume) on termite mound materials compared to surface soils from the same areas. The increase was correlated to the phosphorus and nitrogen level of the mound and soil material used. Negative results have also been reported by Nye (1955) and Kang (1978), in Nigeria, where growth of annual crops, such as maize was poorer in the soil mound or levelled mounds. In Zaire, Pace (2019) reported that when the material brought up by the termite from the subsoil is particularly infertile, the mounds (mainly if they are abundant) may present a serious obstacle to cultivation.

Studies of Enagbonma and Babalola (2019) reveals soil from termite mound has been reported to have a higher clay, organic matter and nutrient content than the surrounding soils. Other studies such as those of Maduakor *et al*. (1995); Lisa *et al*, (1995); Konate *et al*, (1999); Brossard *et al*, (2007) also reveal same. Termites can also trigger microbial activities when added to soils (Ndiaye *et al*, 2004; Duponnois *et al*, 2005). Others such as Fageria and Baligar (2004) reported on the higher soil fertility of termite mounds compared to the surrounding Oxisoils of the Cerrado region of Brazil, Lopez (2001) reported a greater amount of available phosphorus, especially in the inner part of the nest of African *Trinerviterms germinates* and South American *Nasutiterms ephratae* than their respective surrounding soil.

2.9 Global Cowpea production and yield

The global production of grain legumes has increased over the decades; the mean annual world grains production reached a high of 75.68 million tonnes during 2008–2017. India is the largest producer of grain legumes accounting for about 24% of the global legume production and holding 32% of the world grain legumes harvested land and accounting for more than a quarter of global production, followed by Myanmar, Canada, and China contributing 7% each. Africa as a whole, account for 22% of the global production of grain legumes (Kebede, 2020a). According to the report of FAOSTAT (2016), the global area under cultivation of some of the major legumes (groundnuts, chickpea, pigeon pea, common bean, cowpea, and soybean) in 2014 was about 220 million hectares (ha), with the production of about 430 million metric tons (MT) at average productivity of 1.7 MT per ha (beans = 1.6, chickpea = 1.4, cowpea = 0.44, groundnut = 2, pigeon pea = 1.4, soybean = 1.8).

During 2014 production year, the area coverage in Sub-Saharan Africa (SSA) was about 36 million ha (about 16.3 percent of global area), with production of about 27 million MT (around 6 percent of global production) at an average productivity of 0.89 MT per ha (beans = 0.94, chickpea = 0.98, cowpea = 0.48, groundnut = 0.96, pigeon pea = 0.86, soybean = 1.01). The Eastern Africa region accounted for 8.8 million ha (about 24.4 percent of the SSA area), 7.7 million MT (about 28.6% of SSA production), with an average productivity of 1.00 MT per ha (beans = 1.29, chickpea = 1.01, cowpea = 0.54, groundnuts = 1.15, pigeon pea = 0.78, soybean = 1.28) (Ojiewo et al., 2018).

Among the legume crops, cowpea is grown in 45 countries across the world (Abate et al., 2011). An estimated 14.5 million ha of land is planted to cowpea each year worldwide, with over 6.5 million metric tons produced annually. The world average yield is estimated at 450 kg per ha with most of the world cowpea production coming from Africa where countries such as Nigeria, Niger, Burkina Faso, Tanzania, Cameroon, Mali, and Kenya are the most important producers. Nigeria and Niger each cultivate over 4 million ha and account for more than 45% and nearly 15% of the world's total production, respectively (Abate et al., 2011; Boukar et al., 2018; Kamara et al., 2018). Myanmar and Sri Lanka are the only two countries that produce substantial amounts of cowpea in the world. Besides, production in Myanmar has shown sustained growth whereas Sri Lanka's production has declined over the years (Abate et al., 2011). According to Kamara et al. (2018), over 12.61 million ha are grown to cowpea worldwide, with an annual grain production of about 5.59 million tons. Africa accounts for 84% of grain production; Nigeria being the largest cowpea producer in the world and accounts for over 2.5 million tons of grain production from an estimated 4.9 million ha. Niger, Burkina Faso and Tanzania are the leading cowpea producer both in terms of area coverage (ha) and production (tons) following Nigeria. Other important production areas include lower elevation areas of eastern and southern Africa and in South America (particularly in northeastern Brazil and in Peru), parts of India, and the southeastern and southwestern regions of North America. Uganda and Kenya are also the largest cowpea-producing countries in eastern Africa (Ojiewo et al., 2018).

This increase in area, production and yield have been made possible by a similar trend in Sub-Saharan Africa, which dominates the world scene. Total area, yield, and production in Sub-Saharan Africa grew at the rate of about 4.3%, 1.5%, and 5.8%, respectively (Abate et al., 2011). Production level in countries like Brazil, Cuba, Ghana, Mozambique, Nigeria, Sri Lanka, Sudan, Zambia, and Zimbabwe is increasing due to availability of improved cowpea varieties (Ngalamu et al., 2015).

2.10 The root zone of cowpea

The root zone of plants is the area of soil and oxygen surrounding the roots of a plant. Roots are the starting point of a plant's vascular system. Water and nutrients are pulled up from the oxygenated soil around the roots, called the root zone, and pumped into all the aerial parts of the plant. A proper and healthy plant root zone is spread out past the drip line of a plant (Seiwa, 2002). The drip line is a ring-like area around the plant where water runs off from the plant and into the ground. As plants root and grow, the roots spread out toward this drip line in search of the water that runs off the plant. In established plants, this drip line area of the root zone is the most efficient area to water the plant in a drought. In many plants, the roots will branch out densely and grow up toward the soil's surface around the drip line to absorb as much rainfall and runoff as the roots and root zone can hold. Plants that root deeply, depend more upon deep groundwater, and will have a deeper root zone.

The root system of cowpea was larger and deeper than mungbean. In the dry season without irrigation, the depth of rooting might have a major influence in determining the potential supply of soil water that is available to the crop (Gregory, 2006). Greater depth of cowpea roots on the sandy soil profile can increase access and use of soil moisture in deep soil layers (Matsui and Singh, 2003). This character might explain why cowpea can grow well in the dry-season without irrigation on sandy soils that have a shallow standing water table after rice harvest. Sangakkara et al. (2001) reported that cowpea had a more extensive root system than mungbean, a characteristic of a drought-tolerant species, and this trait facilitates the extraction of moisture from dry soils.

Cowpea generally is strongly taprooted. Root depth has been measured at 95 in. 8 weeks after seeding. A matured cowpea has the root depth at 18-24 inches (Matsui and Singh, 2003).

2.11 Environmental requirement of cowpea

Cowpea is a warm-season crop well adapted to many areas of the humid tropics and temperate zones. It tolerates heat and dry conditions, but is intolerant of frost. Germination is rapid at temperatures above 65°F; colder temperatures slow germination. Cowpeas are grown under both irrigated and non-irrigated regimes. The crop responds positively to irrigation but will also produce well under dryland conditions. Cowpea is more drought resistant than common bean. Drought resistance is one reason that cowpea is such an important crop in many underdeveloped parts of the world. If irrigation is used, more vegetative growth and some delay in maturity may result. Application rates should insure that the crop is not overwatered, especially in more northern latitudes, as this will suppress growth by lowering soil temperatures. The most critical moisture requiring period is just prior to and during bloom. According to Davis et al., (2003), cowpea performs well on a wide variety of soils and soil conditions, but performs best on well-drained sandy loams or sandy soils where

soil pH is in the range of 5.5 to 6.5.

2.12 Nodulation and Nitrogen Fixation

Cowpea roots normally become infected with *Bradyrhizobia japonicum* bacteria, which cause formation of round or oval shaped root growths termed nodules (Sarkodie-Addo *et al.,* 2006; Nastasija *et al.,* 2008). Millions of these bacteria are located within each nodule and provide much of the cowpea plant's nitrogen supply through a process called nitrogen fixation. Through nitrogen-fixation, the bacteria change non-available N_2 gas from the air into nitrogen products that the cowpea plant can use. The plant in turn provides the bacteria's carbohydrate supply. A relationship such as this, where both the bacteria and plant profit from the other, is called a symbiotic relationship. Nodules actively fixing nitrogen for the plant appear pink or red on the inside, but are white, brown, or green if N-fixation is not occurring.

Cowpea is a legume and normally provides itself nitrogen, through a symbiotic relationship with nitrogen fixing bacteria of the species, *Bradyrhizobium japonicum* (Sarkodie-Addo *et al.,* 2006; Nastasija *et al.,* 2008). Bacteria present in soybean root nodules will fix nitrogen from the atmosphere, normally supplying most or all nitrogen needed by the plant. Cowpea grown on soil where well nodulated cowpea has been grown in recent years will probably not require inoculation; however, if there is any question about the presence of *Bradyrhizobium* bacteria, inoculation is recommended (Darryl *et al.,* 2004; Nastasija *et al.,* 2008).

The amount of nitrogen that a plant can fix depends on the variety, the productivity of *Bradyrhizobium* bacteria, the soil and the climatic conditions. Cowpea is capable of fixing between 60kg and 168kg of nitrogen per hectare per year under suitable conditions (Darryl *et al.,*2 004).

Cowpea nitrogen requirements are met in a complex manner, as it is capable of utilizing both soil nitrogen, in the form of nitrate and atmospheric nitrogen, through symbiotic nitrogen fixation. In the symbiotic relationship, carbohydrates and minerals are supplied to the bacteria by the plant, and the bacteria transform nitrogen gas from the atmosphere into ammonium and nitrate for use by the plant.

Plant population is one factor that may influence how much residual nitrogen soybean is contributing to a cropping system. Estimated nitrogen fixation of determinate cowpea was approximately, increased from 200 to 280 kg/ha, when plant population was increased from 48,500 to 194,000 plants ha-1 respectively (Ennin and Clegg, 2001).

The process of nitrogen fixation requires the presence of the right species of the nitrogen fixing bacteria in the soil, and they are often attracted to the roots by chemical signals from the cowpea root (Bernhard, 2010). Once in contact with the root hairs, a root compound binds the bacteria to the root hair cell wall. The bacteria release a chemical that causes curling and cracking of the root hair, allowing the bacteria to invade the interior of the cells, and begin to change the plant cell structure to form nodules. The bacteria live in compartments of up to 10,000 in a nodule, called bacteroids. The nitrogen fixation is aided by an enzyme, nitrogenase which takes place in an environment without oxygen, through a transfer compound, leghemoglobin. And this results in a pink-red colour of nodule interiors, an indication of active fixation of nitrogen (Lindermann and Glover, 2003). Ferguson *et al.,* (2006) reported that cowpea plant will effectively utilize soil residual nitrate and nitrogen mineralized from soil organic matter, obtaining 25 to 75 percent of plant nitrogen, with the balance supplied from symbiotic fixation.

Legume nodules that are not fixing nitrogen usually turn white, grey or green and may actually be discarded by the plant. This may be as a result of inefficient Rhizobium strain, poor plant nutrition, pod filling or other plant stresses. Nastasija *et al.*, (2008) have outlined the following as limiting factors to N-fixation:

- A temperature of 16ºC to 27ºC is ideal, while levels above or below this reduce bacterial activity and slow the establishment of the N-fixing relationship.
- When soil N levels are too high, nodule number and activity decrease. Roots do not attract bacteria or allow infection; hence, nitrogen fixation is limited.
- Poor plant growth does not allow the plants to sustain nodules therefore sacrificing nodule activity.
- If soil pores are filled with water, and not air, there will be no nitrogen to be fixed.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site and climatic condition

The study was conducted at the University of Education, Winneba, Mampong – Ashanti campus now Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development between September, 2018 to July, 2019. Mampong-Ashanti lies at 457.5m above sea level and falls within the forest-savannah transitional zone that is the southern rain forest and Guinea Savannah belt of the North. Mampong lies between latitude 7° and 8° N of the equator and longitude 1° and 2° W (Ghana Metrological Agency-Mampong Ashanti, 2019). Rainfall distribution in the area is bimodal and classified into major and minor rainy seasons. The major season commences from April to July and the minor season from early September to late November. The average annual rainfall range is between 1270 and 1525mm with a monthly mean rainfall ranging between 105 and 127mm. The monthly day temperature is about 25-32 ℃ (Ghana Metrological Agency-Mampong Ashanti, 2019).

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3.2 Soil and vegetation

The soil type at the project site is sandy loam which is devoid of hard solid mass which may hinder cultivation. It is well drained with good water holding capacity. The soil is of the savannah ochrosol type which belongs to the Bediesi series known as Chromic Luvisol (FAO/UNESCO, 1990) and derived from the voltaian sandstone. According to Acquah (1978), the soil has a characteristic deep brown colour, free from concretions, which could delay cultivation. It is well-drained, friable, medium textured and easy to cultivate by hand or machine with a pH between 6.0 and 6.5.

The vegetation cover of the site comprised nut grass (*Cyperus rotundus*), elephant grass (*Pennisetum purpurem*), guinea grass (*Pannicum maximum*), giant star grass (*Cynodon plectostachyum*) and *Imperata cylindrical* as the dominant species. Others such as *Brachiaria spp, Boerhavia and Acanthospermum hispidum* are also found.

3.3 Treatments

Three treatments namely topsoil (control), subsoil and termite mound soil were considered for this study.

3.3.1 Preparation of treatment

The topsoil was removed from 0 - 30cm deep. The dug-up soil was put in thirty-two 12 litre buckets. A 2-litre space was left on each bucket for watering and removal of weeds. Subsoil (31cm-96cm) was dug up and used as one of the treatment. Subsoil was also placed in thirty-two 12 litre buckets leaving a 2-litre space in each. Termite mounds within the same area were dug up and lumps were broken. Seventeen (17) mounds were broken down and used for each experiment. Thirty-two (32) 12 litre buckets were filled with the termite mound soil. All the buckets were watered three times and allowed to stand for eight days before planting was done. The soil types were changed during each cropping season.

3.4 Experimental design

The study was a pot experiment arranged in a Randomised Complete Block Design (RCBD) with four replications. A total of ninety-six (96) 12 litre buckets were used (32 for each treatment) as experimental pots. There were three treatments in total. The total land area used was eighty (80) m^2. The experiments were carried out during the minor season (September to November 2018) and major season (April to July 2019). Four Seeds were sown per hill in each prepared pot. Cowpea *var* Agyenkwa which was developed by Crop Research Institute has early maturing (65 days), high yielding, fast-cooking, nutritious and exhibit tolerance to drought and common insect-pests diseases of cowpeas. This was used as the test crop. Germination and emergence of seedlings took place five to ten days after sowing.

3.5 Agronomic Practices

3.5.1 Thinning

Thinning out was done to approximately 2 plants per pot, 14 days after sowing when the soil was moist and seedlings well established.

3.5.2 Weed Control

Weeding was done manually by hand picking at 22 days after planting. Weeding was repeated three times before harvesting.

3.5.3 Pest Control

There were incidences of pod suckers at the pod filling stage, which warranted control measures. For both experiments, sprayings were carried out using Lambda super 2.5 EC (containing 25g active ingredient Lambda cyhalothrin per litre) at the rate of 600 ml per hectare with a Knapsack sprayer, at a recommended 14 days interval to control the insects till pods were completely filled.

3.6 Laboratory analytical procedures

The laboratory analysis was carried out at the Soil Research Institute Analytical Services Division at Kwadaso in Kumasi.

3.6.1 Determination of soil physical and hydrological properties

Soil sampling was randomly done by collecting soil samples from each treatment using core samplers. A sample was taken per each treatment. Termite mound soils were dug out, broken and the same volume was placed in the core samplers for the analysis.

3.6.1.1 Soil bulk density (ρ_b)

Sampling for the bulk density of the three treatments was done by taking the same mass of the top soil, sub soil and termite mound soil. The soil samples were air dried and ground gently to pass through a 2mm sieve for analysis of bulk density. The three samples were placed in containers and watered to point of saturation. The samples were allowed to stand for seven days for the particles to settle. Core samplers were used to take the soil samples, weighed and oven dried at 105 degrees Celsius for 24 hours to a constant mass. The oven dried soils were weighed and the dry bulk densities were calculated by dividing the oven dried mass by the total volume of the soil. Thus, the dry bulk density P_b was calculated from the formula:

$$\rho_b = \left(\frac{M_s}{V_t}\right)$$

Where,

M_s = oven dry mass of soil

V_t = total volume of the soil

3.6.1.2 Soil moisture content determination

Moist soil samples were taken from the field two days after a heavy rainfall when the soil was assumed to be at or near field capacity, defined as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially ceased which is attained in the field after 48–72 hours of saturation (USDA-NRCS, 2008). Soil samples were collected with a core sampler from pots and sent to the laboratory where they were weighed to find their initial masses. They were then oven-dried at a temperature of 105°C to a constant mass M_s. The loss of water upon drying constituted the mass of water M_w contained in the sample. This gave the gravimetric water content which is the mass of water per mass of dry soil in a given sample. The gravimetric moisture was calculated using the relation (Bilskie, 2001)

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

Where,

M_s = the mass of the solid components of the soil

M_w = the mass of water contained in the soil

$M_w = M_t - M_S$

M_t = total mass of moist soil

3.6.1.2.1 Volumetric Moisture

It is the volume of water per volume of soil. It was determined by the relation (Hillel, 1982).

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

Where,

θ_v = volumetric moisture content

θ_g = gravimetric moisture content

ρ_b = dry bulk density

ρ_w = density of water (assumed to be 1.0 g/cm^3)

3.6.1.3 Soil texture

The hydrometer method was used for soil texture determination (Anderson and Ingram, 1993). To a 50 g soil, a dispersing agent, sodium hexametaphosphate (Calgon) was added. The suspension was shaken on a Stuart reciprocal shaker for 18 hours at 400 rpm. The suspension was then transferred into 1000 ml sedimentation cylinder and topped up to mark with distilled water. The density and temperature of the suspension were measured using a hydrometer and thermometer at 40 seconds and 3 hours, respectively.

Calculations; (Anderson and Ingram, 1993).

% Sand = 100 – [Ha – 0.2 x {Ta – 20} – 2.0] x 2

% Clay = [Hb + 0.2 x {Tb – 20} – 2.0] x 2

% Silt = 100 – {Sand (%) + Clay (%)}

Where,

Ha = 1st hydrometer reading.

Hb = 2nd hydrometer reading.

Ta = 1st temperature reading of suspension.

Tb = 2nd temperature reading of suspension.

The texture triangle was then used to determine the textural class.

3.6.1.4 Total porosity (f)

Total porosity was calculated from the formula (Hillel, 1982);

$$f = 1 - \left(\frac{\rho_b}{\rho_s}\right)$$

Where,

f = total porosity

ρ_b= bulk density

ρ_s= particle density (assumed to be 2.65 g/cm^3 for all soils)

3.6.1.4.1 Aeration porosity (ξ_a)

Soil aeration porosity was calculated from the formula (Klute, 1986):

$$\xi_a = f - \theta_v$$

Where,

ξ_a = aeration porosity

f = the total porosity

θ_v is volumetric water content

3.6.2 Soil chemical properties

Soil sampling for the chemical analysis was done randomly by selecting three pots from each treatment. Surface litter on each pot was removed. Auger was driven into the soil at a depth of 15cm to draw the soil samples. Measured quantities of the samples were placed in clean polythene bags. The polythene bags were labelled on the outside with permanent pen. The samples were quickly sent to the laboratory to prevent chemical changes that may occur in the samples.

3.6.2.1 Soil pH

Soil pH was measured potentiometrically which is in equilibrium with soil suspension (Chapman and Pratt, 1961). The apparatus used were: glass electrode and pH meter. Regents used were: Distilled water, potassium chloride, calcium chloride, Buffer solution, beaker, 2mm sieve, air-dried sample of soil and a glass rod. A 20g weight air-dried soil was passed through 2mm sieve and put into a 100ml beaker. Fifty (50) ml of distilled water was added to it and allowed to stand for 30 minutes with occasional stirring with the glass rod. The electrodes of the pH meter were later inserted into the upper part of the suspension and when the reading had stabilized, the pH was measured.

3.6.2.2 Soil organic carbon

The Walkley-Black method was employed. Regents used were: potassium dichromate, cone, sulphuric acid, orthophosphoric acid, orthophenanthrolime, barium diphenylamine sulfonate and ferrous sulphate. The representative sample was grinded to pass through 2 mm sieve. This was later weighed and transferred into 250ml Erlenmeyer flask. A 10 ml of 0.1667 M $K_2Cr_2O_7$ solution was added from a burette into each flask and swirled gently to disperse the soil. A 20 ml of concentrated H_2SO_4 was also added using an automatic pipette, directing the stream into suspension. The flask was immediately swirled gently until soil and regent were mixed, then swirled more vigorously for one minute. The flask was rotated again and allowed to stand on porcelain for about 30 minutes. About 3-4 drops of the barium diphenylamine sulfonate indicator was added and titrated with 1*M* $FeSO_4$ solution. As the end point was approached, the solution took on a greenish cast and then changed to dark green. Then 0.5ml $K_2Cr_2O_7$ was added from a burette and the titration was completed by adding dropwise the Fe_2SO_4 solution until a stable endpoint was attained. A blank titration was made in the same way. The percentage organic carbon was calculated (Nelson and Sommers, 1982):

$$Organic\ C\ (\%) = \left(\frac{M\ x\ (V1 - V2) x\ 0.39\ x\ mcf}{s}\right)$$

Where,

M = molarity of ferrous sulphate solution for blank titration

V_1 = ml ferrous sulphate solution required for blank

V_2 = ml ferrous sulphate solution required for sample

S = weight of air-dried sample in gram

0.39 = 3 x 10^{-3} x 100 % x 1.33

mcf = moisture correction factor

correction factor (f) = 1.33 (100/75)

Organic matter (%) = Organic C x 1.72

3.6.2.3 Soil total nitrogen

The Kjeldahl method as described by Bremner and Mulvaney (1982) was used. Total N includes the entire organic and inorganic N in the soil (NO_3 - N and NH_4 - N). A mass of 1.4 g of finely ground (0.5 mm sieve) air-dried soil was weighed, and transferred to digestion tubes or Kjeldahl flask. A 5 ml of the digestion mixture was added and shook carefully until all the soil material was moistened. Two blanks and a reference sample were included and allowed to stand for at least 2 h. The tubes in the Kjeldahl flask were put in the rack and heated at 100 °C for at least 2 h. The tubes were removed and allowed to cool. Three (3) 10 ml aliquot of H_2O_2 were added successively and mixed thoroughly. The material was digested gently at first and more vigorously later. When the mixture was clear, it was removed and tubes or flasks cooled. The flask was then topped up to the 100 ml mark. A suitable aliquot was then taken for total N determination. Boric acid-indicator solution (20 ml) was put into 250ml beaker and placed beneath the condenser tip. NaOH (38 %) (20 ml) was added to a suitable aliquot and distilled for about 7 minutes during which approximately 75 ml of distillate was produced. The distillate was then titrated with 0.01M HCl until the colour changed from green to pink. The percentage N was then calculated as follows:

$$\text{Soil total N (\%)} = \frac{(a - b) \times M \times 1.4 \times mcf}{s}$$

Where,

a = ml HCl required for sample titration

b = ml HCl required for blank titration

S = weight of air-dry sample in grams

M = molarity of HCl

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

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

3.6.2.4 Soil available phosphorus

The Bray 1 method (Bray and Kurtz, 1945) was employed for the determination of available phosphorus in the soil. Five grams soil was weighed and 30 ml of Bray 1 solution added and shaken for 15 minutes on a Stuart reciprocal shaker. The mixture was filtered through Whatman No. 42 filter paper. A 0, 1, 2, 3, and 5 mg P/L standard series were prepared. A 5 ml aliquot of the extract and 5 ml each of ammonium molybdate (colouring agent) and ascorbic acid were measured and mixed uniformly in a test tube and the solution allowed to stand for 15 minutes for maximum blue colour development. The absorbance was measured using the double beam spectrophotometer (Specs) at 600 nm wavelength. A standard curve was plotted using the standard values against the corresponding concentrations.

Calculation;

Soil available P (mg/kg) = $\frac{(x - y) \text{ x } V \text{ x } df}{s}$

Where,

x = mg P/L in soil extract

y = mg P/L in blank

V = volume of extract

df = dilution factor

s = weight of soil

3.6.2.5 Exchangeable cations

The exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) were extracted using ammonium acetate (1.0 *M* NH_4OAc) extract at pH 7 according to Thomas (1983).

3.6.2.5.1 Extraction of exchangeable bases

Ten grams of soil was weighed into a leachable tube and 100 ml of 1.0 *M* NH_4OAc added and leached.

3.6.2.5.1.1 Exchangeable calcium and magnesium

An aliquot of the extract (10 ml) was transferred into a conical flask. This was made up to 50 ml with distilled water. To this, a 1.0 ml each of 2 % potassium ferrocyanide, hydroxylamine hydrochloride, potassium cyanide and 10 ml of ethanolamine buffer were added. The mixture was titrated to a blue colour end point with 0.01 *M* EDTA and 0.2 ml Eriochrome Black T indicator. Magnesium titre value was determined by subtracting the titre value of calcium from this titre value. Calcium was determined using 10 ml aliquot of the extract and made up to 50 ml with distilled water. A 1 ml each of 2 % potassium ferrocyanide, of hydroxylamine hydrochloride and 2 %

potassium cyanide were added. 10 % KOH (10) ml and cal red were added. The mixture was titrated using 0.01 *M* EDTA to a pure blue colour end point.

Calculation,

$$Ca + Mg \text{ (or Ca only) } (cmol_{(+)}/ \text{ kg soil}) = \frac{(V_1 - V_2) \times 0.01 \times 1000}{0.1 \times S}$$

Where,

V_1 = volume of 0.01 *M* EDTA used in the titration of sample extract

V_2 = volume of 0.01 *M* EDTA used in the titration of blank

S = soil sample weight

0.01= EDTA concentration.

3.6.2.5.1.2 Exchangeable potassium and sodium

Flame photometry procedure was used to determine the exchangeable potassium and sodium in the leachate. Standard series 0, 2.5, 5.0, 7.5 and 10 mg/L for K and Na were prepared from 1000 mg/L K and Na. Sodium and potassium and sodium in the leachate were determined by flame photometer at 589.0 and 766.5 nm wavelengths respectively.

Calculation:

$$\text{Exch. K } (cmol_{(+)} /\text{kg soil}) = \frac{(x - y) \times 250 \times mcf}{10 \times 39.1 \times s}$$

$$\text{Exch. Na } (cmol_{(+)} /\text{kg soil}) = \frac{(x - y) \times 250 \times mcf}{10 \times 23 \times s}$$

Where,

x = mg K /L or Na in the diluted sample.

y = mg K /L or Na in the diluted blank sample.

s = weight of soil in grams.

mcf = moisture correcting factor.

Total exchangeable bases (TEB) were determined by the summation of the exchangeable bases;

TEB ($cmol_{(+)}$ /kg soil) = $K^+ + Ca^{2+} + Mg^{2+} + Na^+$

3.6.2.6 Determination of exchangeable acidity

The soil sample was extracted with unbuffered 1.0 *M* KCl solution. Ten grams of soil sample was weighed into a 200 ml plastic bottle and 50 ml of 1.0 *M* KCl solution added. The mixture was shaken on a reciprocating shaker for 2 h and filtered. An aliquot of 25 ml of the extract was pipetted into a 250 ml Erlenmeyer flask and 4-5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 *N* NaOH until the colour just turned permanently pink. A blank was also included in the titration.

Calculation:

Exchangeable acidity ($cmol_{(+)}$ /kg soil) = = $\frac{(a - b) x\ M\ x\ 2\ x\ mcf}{w}$

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

3.6.2.7 Effective Cation exchange capacity (ECEC)

This was calculated by summation of the exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and exchangeable acidity.

3.7 Assessment of growth parameters

3.7.1 Plant height

The mean plant height for each treatment was measured using a meter rule. The measurement was taken from the soil level to the tip of the terminal leaf at two weeks intervals from the 3^{rd} week to 11^{th} week. Measurements were done on four randomly tagged plants from the inner rows of each replication of the treatments.

3.7.2 Stem diameter

The mean stem diameter for each treatment was determined using the vernier caliper. Measurements were taken 5cm from the base of the plant at two weeks interval from the 3^{rd} to 11^{th} week on the same plants used for plant height determination.

3.7.3 Number of leaves

Number of leaves borne on each sampled plant was counted and mean value calculated and expressed as number of leaves per plant.

3.7.4 Days to 50% flowering

The number of days taken from planting to 50 per cent flowering of the plants was recorded as days to 50 per cent flowering.

3.8 Assessment of yield parameters

3.8.1 Number of pods per plant

Four randomly tagged plants from the inner row of each replication were taken. All the pods were counted and the average number of pods per plant calculated.

3.8.2 Number of seeds per plant

The number of seeds per plant was determined by taking the four randomly selected plants. Pods were opened at harvest, seeds counted and the average number of seeds per plants was calculated.

3.8.3 Hundred- seed weight (g)

Hundred-seed weight was determined by randomly counting 100-seeds from the selected four plants at harvest. These were weighed to represent the 100-seed weight.

3.8.4 Grain yield

Grain yield per hectare was determined by threshing the harvested plants from the selected pots. The resulting weights, in grams (g) per metre square were then extrapolated to kilogram per hectare to get the average grain yield per hectare.

3.8.5 Nodule count and effectiveness

Sets of three sampled plants from each plot were taken 35 days after sowing to assess nodulation. The samples were carefully dug out and gently washed in a bowl of water to remove all adhering soil particles to allow identification and counting of nodules on the root.

3.9 Data analysis

Statistical analysis of the data obtained was performed using the GenStat statistical package (edition 12). Analysis of variance (ANOVA) was performed on all parameters separately. The least significant difference (LSD) test was used for mean separation at 5 % probability level. Relationships among soil properties were determined by correlation analysis. The significance of the relationships was tested at 5 % level of probability.

CHAPTER FOUR

4.0 RESULTS

4.1 Climatic Condition at the Experimental site

The total monthly rainfall for the minor season of 2018 was 511.5 mm with the highest rainfall recorded in the month of August and September (Table 4.1a). The mean minimum monthly temperature for the 2018 minor season was between 22^0C to 24^0C and the maximum recorded temperature ranged from 29^0C – 33^0C. The mean monthly relative humidity of the minor season fluctuated from 93 % - 96 % at 06: 00 HR GMT and 53% - 76% at 15: 00 HR GMT. The total rainfall recorded in the major season of 2019 was 1064.2mm with the highest rainfall recorded in the month of June (376. 7mm) with minimum in the month of March. The mean minimum temperature ranged from 22^0C – 23^0C and the maximum temperature from 28^0C – 33^0C for the major season, whiles the mean monthly relative humidity alternates from 93 % - 98% at 06:00HR GMT to 57% - 73 % at 15: 00 HR GMT (Table 4.1b). The rainfall pattern was bimodal with the major season occurring from March to July and the minor season from September to November (Ghana Meteorological Agency, Mampong Ashanti, 2019). The total, average temperature and relative humidity in the major season of 2019 were slightly higher than that for the minor season of 2018.

Table 4.1a: Climatic conditions during the 2018 minor season

Month	Total monthly rainfall (mm)	Mean monthly Humidity % (Hours GMT		Mean monthly Max & Min Temperature (°C)		
		06: 00	15:00	Min.	Max	Mean
August	192.6	95	69	22	29	25.5
September	170.7	95	76	22	30	26.0
October	57.1	95	63	24	32	28.0
November	18.3	94	55	23	33	28.0
Total	438.7					

Source: Meteorological service Department, Mampong Ashanti, 2018.

Table 4.1b: Climatic conditions during the 2019 major season

Month	Total monthly rainfall (mm)	Mean monthly Humidity % (Hours GMT		Mean monthly Max & Min Temperature (°C)		
		06: 00	15:00	Min.	Max	Mean
March	110.9	93	57	23	33	28.5
April	138.8	95	61	23	33	28.0
May	164.6	96	61	23	32	27.5
June	376.7	98	67	22	29	26.5
July	273.5	97	73	22	28	25.0
Total	1064.2					

Source: Meteorological service Department, Mampong Ashanti, 2019.

4.2 Chemical characteristic of top, sub and termite mound soils

4.2.1 Soil pH in top, sub and termite mound soils

Figures 4.1a and 4.1b present the results of the pH in top, sub and termite mound soils in the major and minor seasons. Generally, soil pH was relatively higher in the major season than in the minor season. In the major season, soil pH was significantly (p <

0.05) higher in the top (5.73) and termite mound (5.62) soils than the sub soil (4.60). However, there was no significant difference ($p > 0.05$) in pH between the top soil and the termite mound soil (Fig. 4.1a). The top soil significantly ($p < 0.05$) gave the highest pH (5.72) followed by the termite soil (5.61) while the sub soil recorded the least (4.58) in the minor season (Fig. 4.1b).

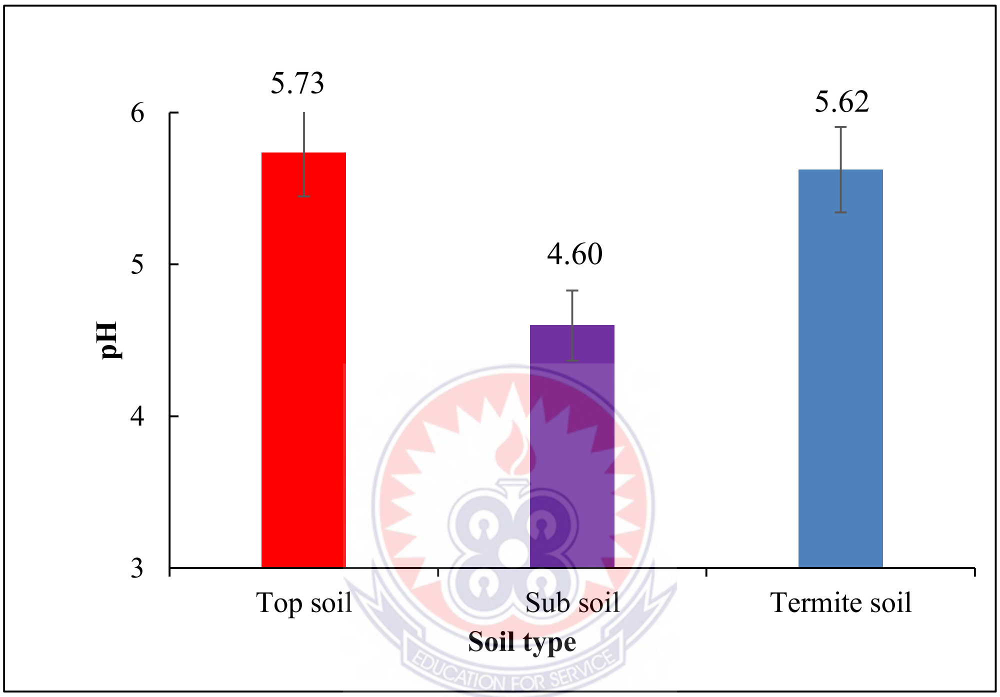

Fig. 4.1a pH of top, sub and termite mound soils in the major season, LSD at 5% was 0.08
Bars = standard error of difference of means (SED) at 5% level of probability

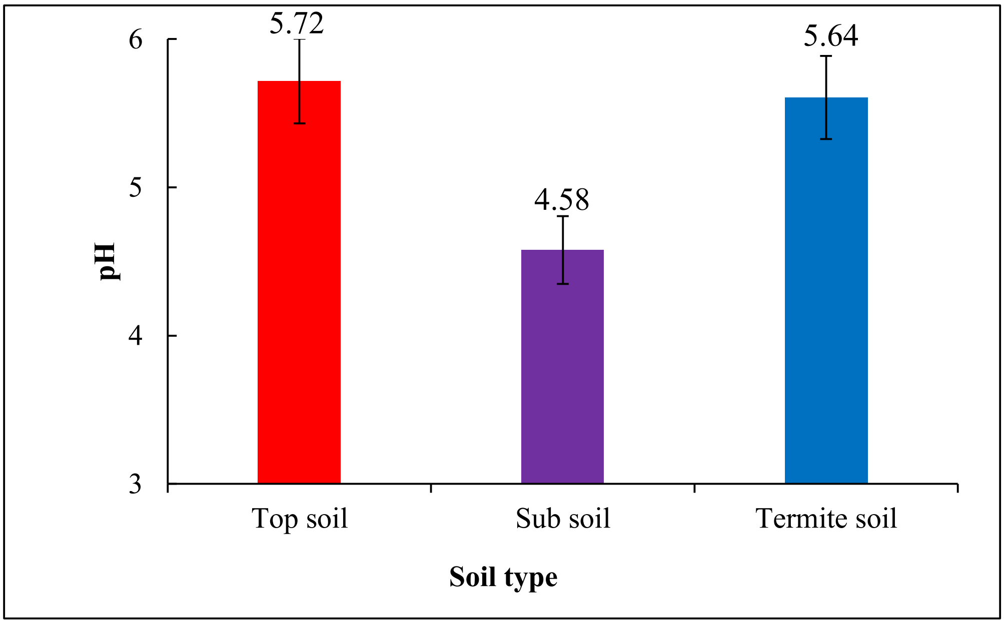

Fig. 4.1b pH of top, sub and termite mound soils in the minor season, LSD at 5% was 0.11
Bars = standard error of difference of means (SED) at 5% level of probability

4.2.2 Soil organic carbon (SOC) in top, sub and termite mound soils

The results of soil organic carbon (SOC) contents in the various soil types during the major and minor seasons are presented in Figures 4.2a and 4.2b. There were significant differences ($p < 0.05$) in SOC contents among the soil types. SOC contents were relatively higher in the major season than in the minor season. During the major season, SOC was about 45 and 95 % more than the termite mound and sub soils respectively (Fig. 4.2a). A similar trend was observed in minor season with the top soil significantly ($p < 0.05$) recording the highest (1.06 %) SOC followed by the termite mound soil (0.64 %) with the sub soil recording the least (0.52 %) (Fig. 4.2b).

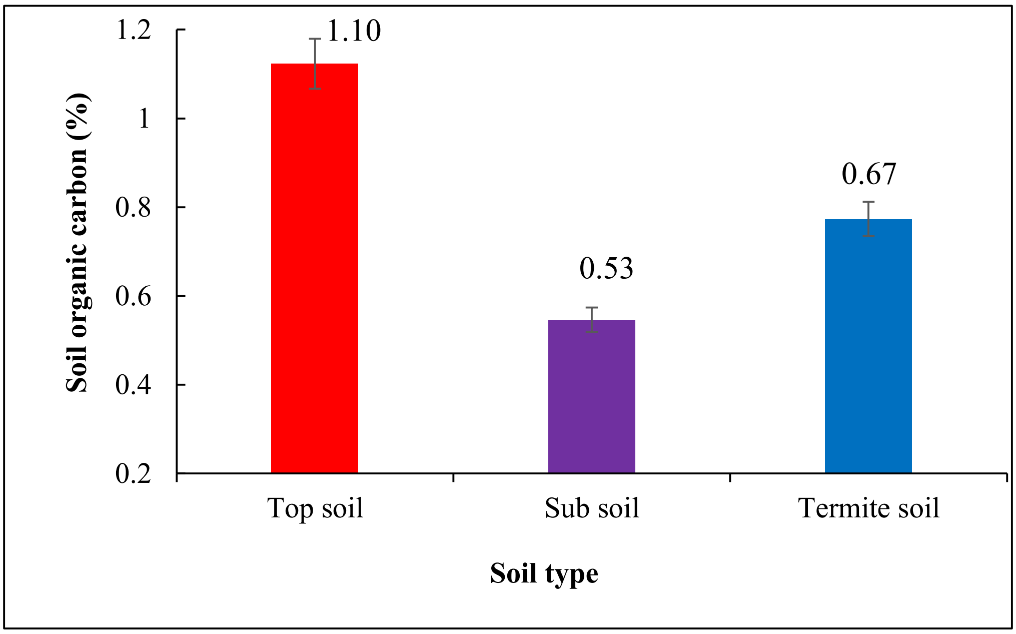

Fig. 4.2a Organic carbon content of top, sub and termite mound soils in the major season, LSD at 5% was 0.07

Bars = standard error of difference of means (SED) at 5% level of probability

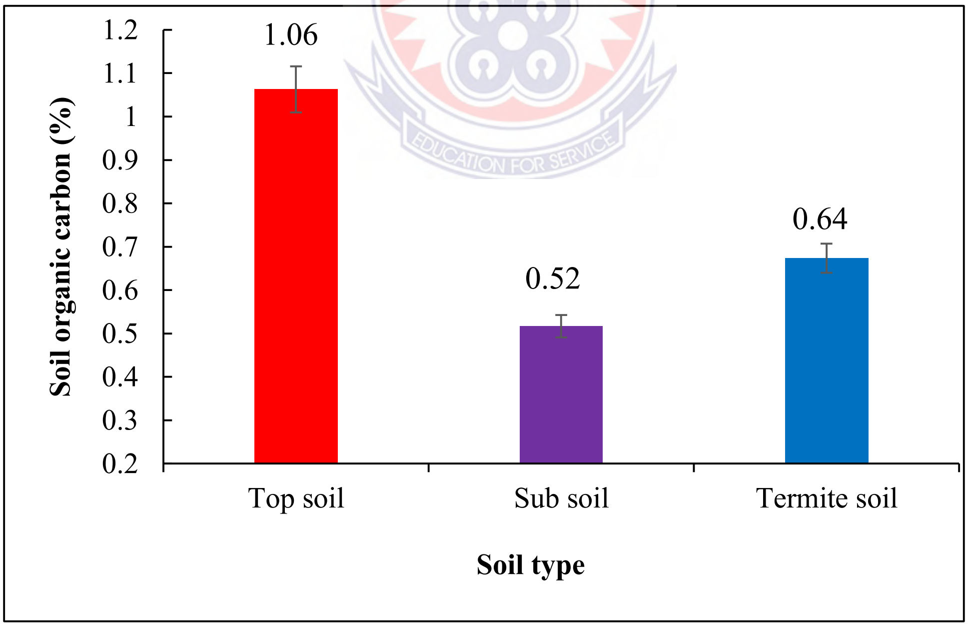

Fig. 4.2b Organic carbon content of top, sub and termite mound soils in the minor season, LSD at 5% was 0.09

Bars = standard error of difference of means (SED) at 5% level of probability

4.2.3 Soil total nitrogen (N) in top, sub and termite mound soils

Soil total nitrogen (N) contents recorded in the various soil types in the major and minor seasons are shown Figures 4.3a and 4.3b. Soil total N content was relatively higher in the major season than in the minor season across the soil types. The top soil significantly ($p < 0.05$) recorded the highest total N (0.2 %) which was about 33 and 72 % more than the termite and sub soils respectively, in the major season. Similarly, as observed in the major season, the top soil significantly ($p < 0.05$) had the highest total N content (0.18 %) followed by the termite mound soil (0.13 %) and the sub soil recording the least (0.07 %) (Fig. 4.3b) in the minor season.

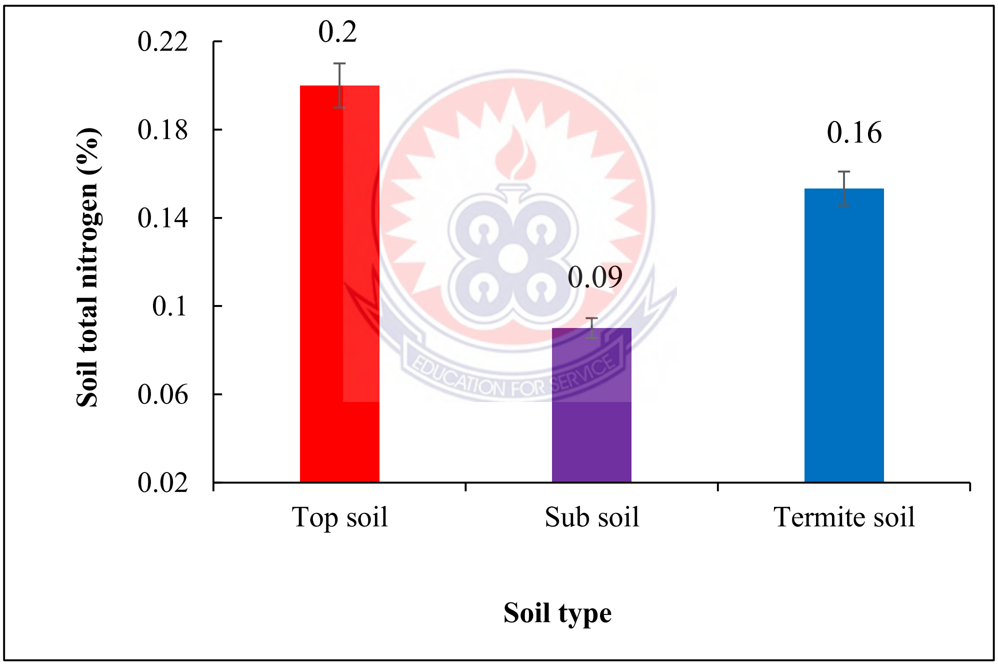

Fig. 4.3a Soil total nitrogen content of top, sub and termite mound soils in the major season, LSD at 5% was 0.03

Bars = standard error of difference of means (SED) at 5% level of probability

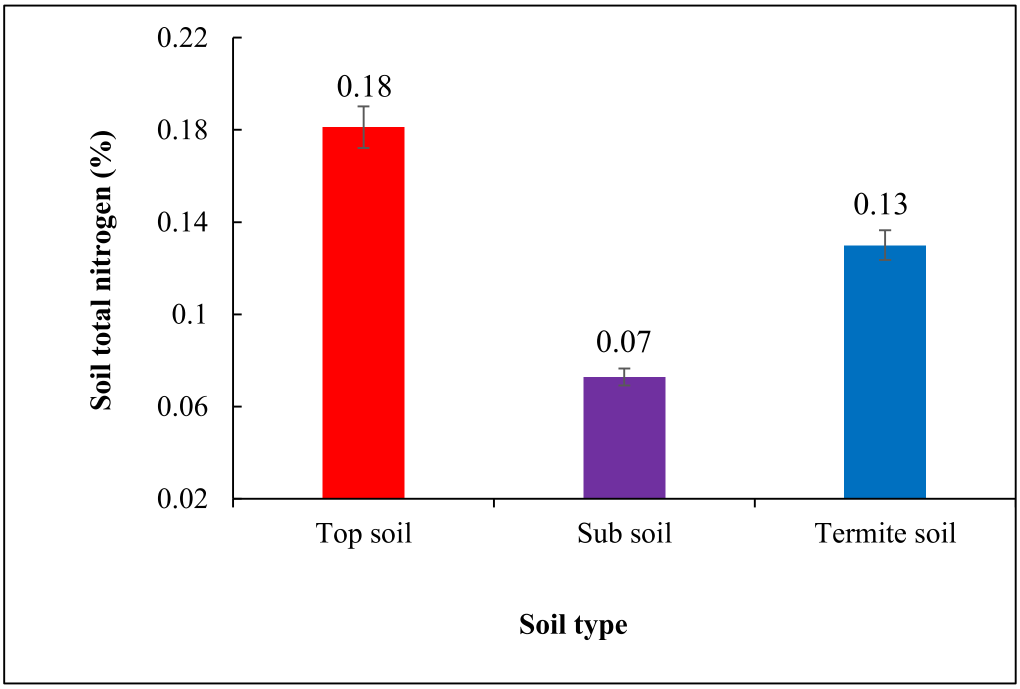

Fig. 4.3b Soil total nitrogen content of top, sub and termite mound soils in the minor season, LSD at 5% at 0.03

Bars = standard error of difference of means (SED) at 5% level of probability

4.2.4 Soil available phosphorus (P) in top, sub and termite mound soils

There were significant differences ($p < 0.05$) in soil P among the soil types in both seasons (Figs. 4.4a & 4.4b) and relatively, higher P were recorded in the major season (Fig. 4.4a) than in the minor season (Fig. 4.4b) across the soil types. The top soil significantly ($p < 0.05$) had the highest P contents in both seasons. These were 13.28 and 11.44 mg/kg in the major and minor seasons, respectively. This was followed by the termite mound soil, 4.92 and 4.5 mg/kg for major and minor seasons respectfully while the sub soil had the least (2.67 and 1.84 mg/kg for major and minor seasons respectfully).

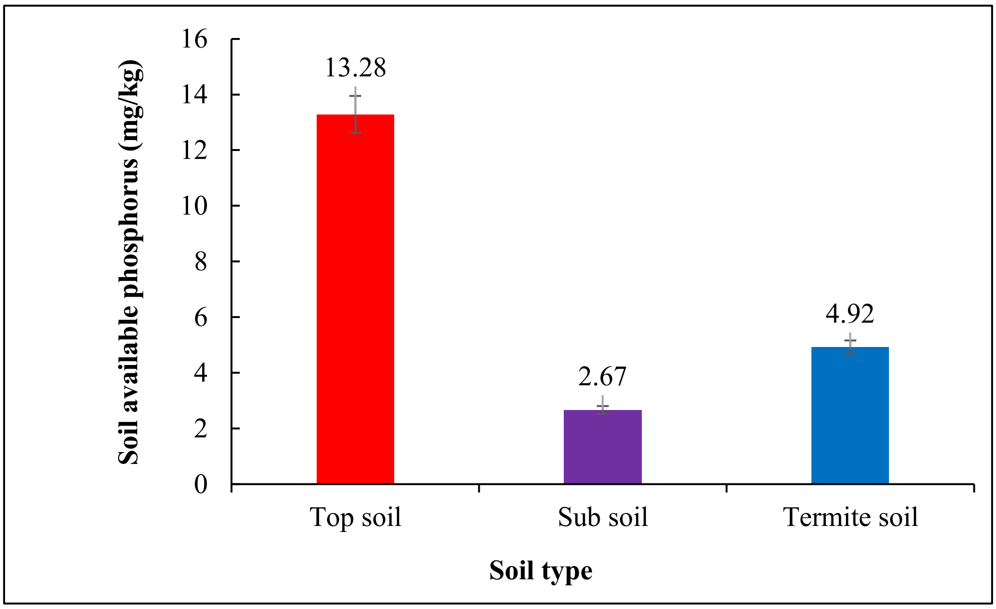

Fig. 4.4a Phosphorus content of top, sub and termite mound soils in the major season, LSD at 5% was 0.89
Bars = standard error of difference of means (SED) at 5% level of probability

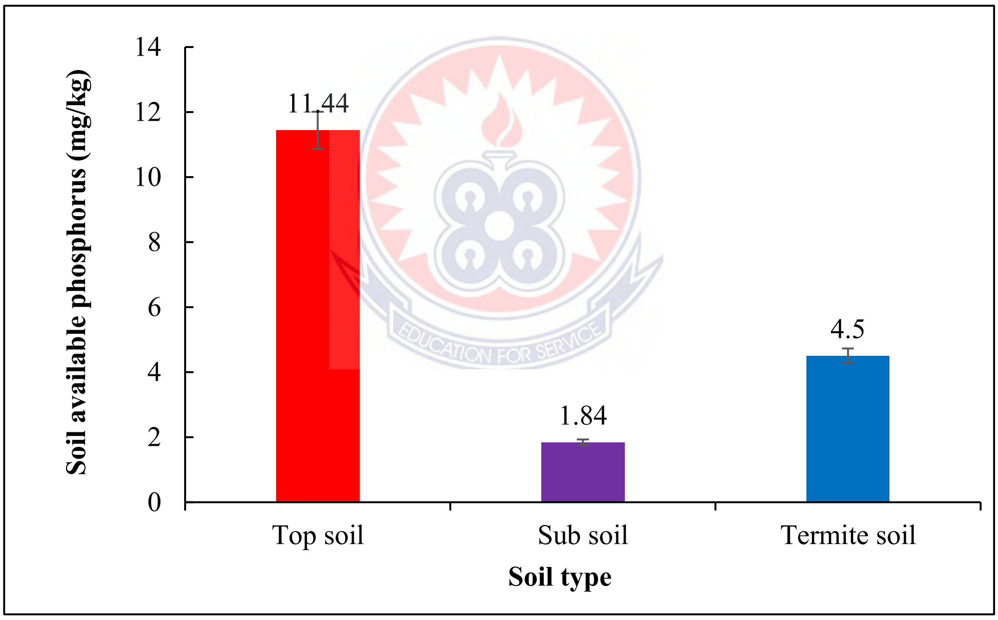

Fig. 4.4b Phosphorus content of top, sub and termite mound soils in the minor season, LSD at 5% was 1.23
Bars = standard error of difference of means (SED) at 5% level of probability

4.2.5 Soil organic matter (SOM) in top, sub and termite mound soils

The results of soil organic matter (SOM) contents in the various soil types during the major and minor cropping seasons are presented in Figures 4.5a and 4.5b. There were significant differences ($p < 0.05$) in SOM contents among the soil types. SOM contents were relatively higher in the major season than in the minor season. During the major season, SOM was about 45 and 85 % more than the termite mound and sub soils respectively (Fig. 4.5a). A similar trend was observed in minor season with the top soil significantly ($p < 0.05$) recording the highest (1.82 %) SOM followed by the termite mound soil (1.10 %) with the sub soil recording the least (0.89 %) (Fig. 4.5b).

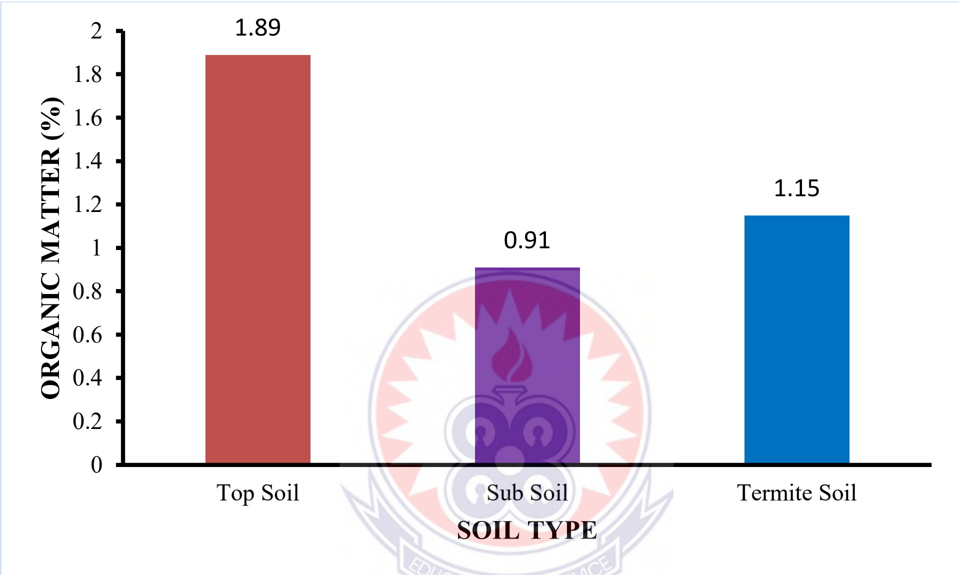

Fig. 4.5a Organic matter content of top, sub and termite mound soils in the major season, LSD at 5% was 0.09

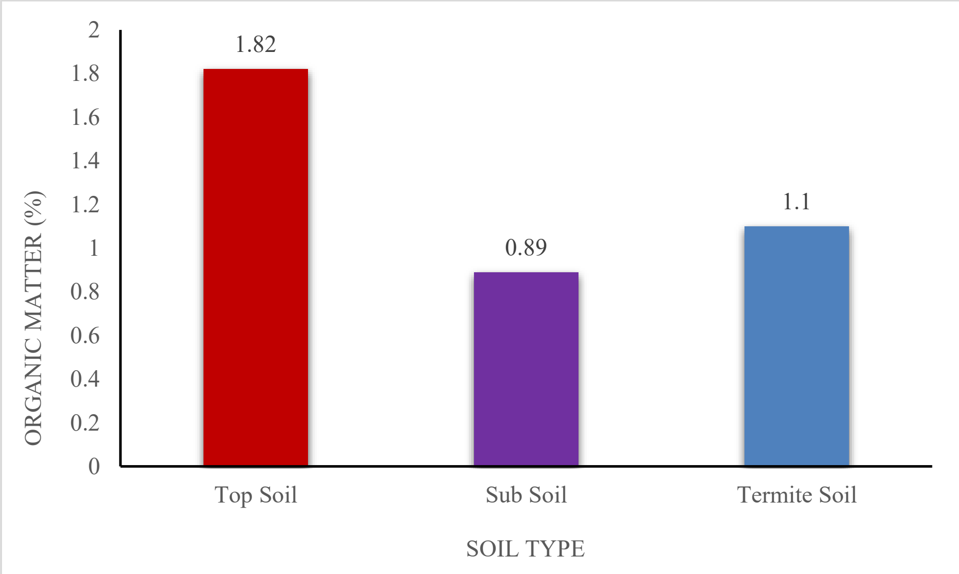

Fig. 4.5b Organic matter content of top, sub and termite mound soils in the minor season, LSD at 5% was 0.10

4.2.6 Soil exchangeable cations, exchangeable acidity, TEB, ECEC and base saturation of top, sub and termite mound soils

Tables 4.2a and 4.2b show exchangeable cations, exchangeable acidity, TEB, ECEC and base saturation in the top, sub and termite mound soils in the major and minor seasons, respectively. There were significant differences among the soil types in both seasons. In the major season, exchangeable Ca^{2+} and K^{+} were significantly ($p < 0.05$) higher in the top and termite mound soils than the sub soil. There was no significant difference ($p > 0.05$) in exchangeable Mg^{2+} between the top (1.69 $cmol_{(+)}$/kg soil) and sub soils (1.69 $cmol_{(+)}$/kg soil each) but were significantly different ($p < 0.05$) from the termite mound soil (1.78 $cmol_{(+)}$/kg soil) (Table 4.2a). TEB was similar ($p > 0.05$) between the top and termite soil, 5.46 and 5.36 $cmol_{(+)}$/kg soil respectively, but were significantly ($p < 0.05$) higher than the sub soil (4.36 $cmol_{(+)}$/kg soil). Exchangeable acidity was higher in the sub soil (0.68 $cmol_{(+)}$/kg soil) than both the top (0.40

cmol$_{(+)}$/kg soil) and termite (0.40 cmol$_{(+)}$/kg) soils. Both ECEC and base saturation observed in the top and termite mound soils were significantly higher than the sub soil (Table 4.2a). A similar trend as observed in the major season was observed in the minor season where TEB, ECEC and base saturation were significantly higher ($p < 0.05$) in the top and termite mound soils than in the sub soil, while exchangeable acidity was higher in the sub soil than the top and termite mound soils (Table 4.2b).

Table 4.2a Exchangeable cations, acidity, TEB, ECEC and base saturation of top, sub and termite mound soils in the major season

Soil type	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	Exchangeable Acidity	ECEC	Base saturation
	(cmol(+)/ kg soil)							(%)
Top soil	3.19	1.69	0.47	0.11	5.46	0.40	5.86	93.18
Sub soil	2.34	1.69	0.20	0.13	4.36	0.68	5.03	86.56
Termite soil	2.86	1.78	0.40	0.32	5.36	0.40	5.76	92.99
LSD (0.05)	0.28	0.07	0.09	0.07	0.32	0.08	0.38	1.03
CV (%)	4.50	1.90	10.80	17.30	2.80	6.80	3.00	0.50

TEB = Total exchangeable bases; ECEC = Effective cation exchange capacity

Table 4.2b Exchangeable cations, acidity, TEB, ECEC and base saturation of top, sub and termite mound soils in the minor season

Soil type	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	Exchangeable Acidity	ECEC	Base saturation
	(cmol(+)/ kg soil)							(%)
Top soil	2.99	1.62	0.49	0.09	5.19	0.45	5.64	92.08
Sub soil	2.11	1.59	0.17	0.11	3.98	0.73	4.71	84.47
Termite soil	2.71	1.74	0.33	0.24	5.02	0.44	5.46	91.89
LSD (0.05)	0.27	0.05	0.02	0.02	0.32	0.08	0.37	1.52
CV (%)	4.60	1.30	3.20	5.50	3.00	6.20	3.10	0.70

TEB = Total exchangeable bases; ECEC = Effective cation exchange capacity

4.3 Hydro-physical characteristics of top, sub and termite mound soils

Some hydrological and physical characteristics of various soil types in major and minor seasons were determined and the results presented in Tables 4.3a and 4.3b. There were significant differences ($p < 0.05$) among the soil types in both seasons. Soil bulk density was significantly ($p < 0.05$) lower in the top soil in both seasons (1.37 and 1.38 g/cm^3

in the major and minor seasons respectively) than the sub and termite mound soils. Again, termite mound soil also had lower bulk density than the sub soil in both seasons. Both gravimetric and volumetric moisture contents were highest in the top soil followed by the termite mound soil while the sub soil had the least in both seasons. Aeration porosity was significantly ($p < 0.05$) highest in the top soil (24.48 %) but similar ($p > 0.05$) between sub soil (19.34 %) and termite mound soil (19.75 %) soils in the major season. A similar trend was observed in the minor season where the top soil had highest aeration porosity with the sub and termite mound soils having similar aeration porosity (Table 4.3b). Total porosity was significantly highest ($p < 0.05$) in the top soil among the soil types in both seasons followed by the termite mound soil and sub soil had the least. The soil texture of the top soil was loamy sand while the sub and the termite mound soils were sandy clay loam.

Table 4.3a Bulk density, moisture content, porosity and texture of top, sub and termite mound soils in the major season

Soil type	ρ_b (g/cm^3)	θ_g (g/g)	θ_v	ξ_a	f	Sand	Silt	Clay	Texture
			(%)			(%)			
Top soil	1.37	13.18	24.02	24.48	48.50	84.1	6.1	9.9	Loamy sand
Sub soil	1.66	11.43	18.04	19.34	37.37	73.9	2.4	23.7	Sandy clay loam
Termite soil	1.60	12.18	19.77	19.75	39.52	70.1	4.0	26.0	Sandy clay loam
LSD (0.05)	0.05	0.33	0.81	1.56	1.42	0.4	0.4	0.5	
CV (%)	1.70	1.50	2.30	4.30	2.00	0.2	4.7	1.1	

ρ_b = soil bulk density; θ_g = gravimetric moisture content; θ_v = volumetric moisture content; ξ_a = aeration porosity; f = total porosity

Table 4.3b Bulk density, moisture content, porosity and texture of top, sub and termite mound soils in the minor season

Soil type	ρ_b (g/cm^3)	θ_g (g/g)	θ_v (%)	ξ_a	f	Sand (%)	Silt	Clay	Texture
Top soil	1.38	11.38	19.45	28.65	48.10	84.00	6.00	10.00	Loamy sand
Sub soil	1.65	9.78	14.83	22.90	37.75	74.00	2.00	24.00	Sandy clay loam
Termite soil	1.58	10.35	16.92	23.52	40.42	70.00	4.00	26.00	Sandy clay loam
LSD (0.05)	0.03	0.36	0.65	1.04	1.19	0.03	0.23	0.35	
CV (%)	1.20	2.00	2.20	2.40	1.60	0.10	2.50	0.80	

ρ_b = soil bulk density; θ_g = gravimetric moisture content; θ_v = volumetric moisture content; ξ_a = aeration porosity; f = total porosity

4.4 Effect of soil type on growth and yield of cowpea

4.4.1 Effect of soil type on plant height of cowpea

There were significant differences ($p < 0.05$) among the soil types in both seasons (Fig. 4.5a & 4.5b). At 3 WAP, there were no significant differences ($p > 0.05$) in plant height among the soil types in both seasons. However, the top soil significantly ($p < 0.05$) produced taller cowpea plants at 5, 7 and 9 WAP than the sub and termite mound soils in both the major and minor seasons. At 11 WAP, no significant differences ($p > 0.05$) in plant height were observed between the top and termite mound soils in the major season which were taller than plants produced by the sub soil (18.43 cm). Similar to the major season, the top and termite mound soils produced plants with similar ($p > 0.05$) heights which were taller than those produced by the sub soil at 11 WAP in the minor season (figure 4.5b).

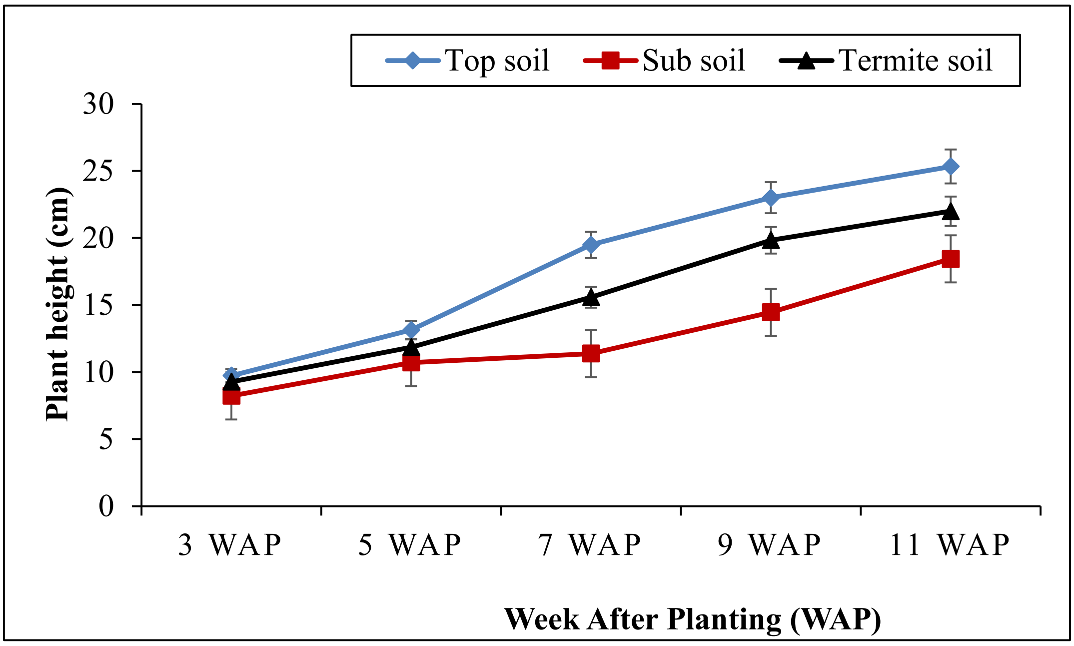

Fig. 4.6a: Effect of soil type on plant height of cowpea in the major season
Bars = standard error of difference of means (SED) at 5% level of probability

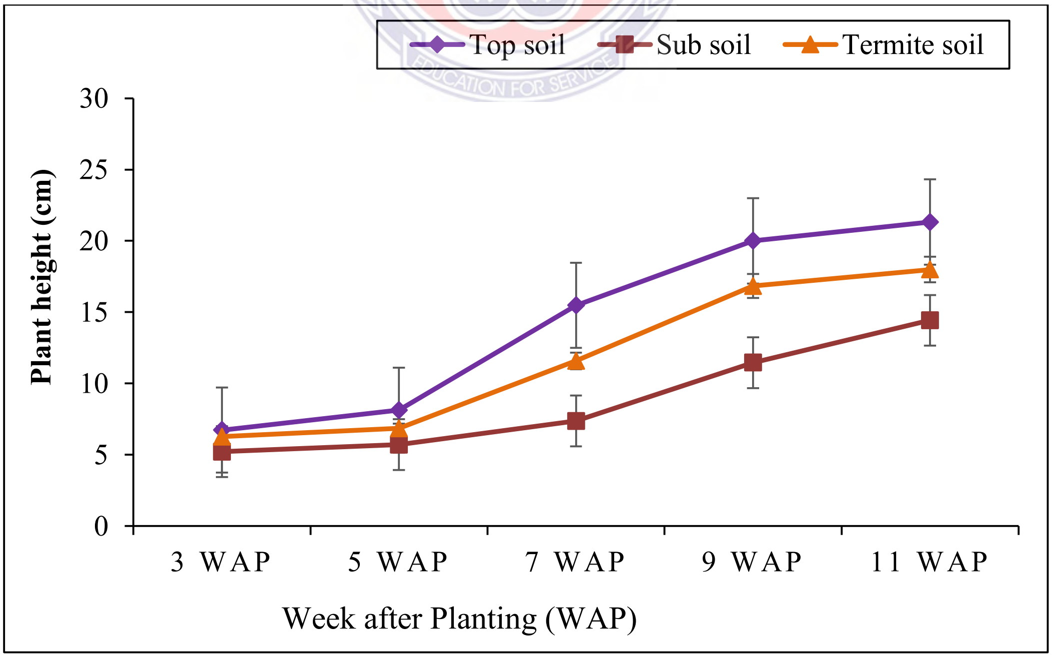

Fig 4.6b: Effect of soil type on plant height of cowpea in the minor season
Bars = standard error of difference of means (SED) at 5% level of probability

4.4.2 Effect of soil type on stem diameter of cowpea

Tables 4.4a and 4.4b show the results of the effect of soil type on stem diameter of cowpea in the major and minor seasons respectively. Significant differences ($p < 0.05$) were observed between the soil types in both seasons. In the major season and at 3, 5 and 7 WAP, the top soil significantly ($p < 0.05$) produced plants with the largest girth followed by the termite mound soil and the sub soil had plants with smallest girth. At the 9 and 11 WAP, no significant differences ($p > 0.05$) in stem diameter were observed between the top and termite mound soils (Table 4.4a). In the minor season, a similar trend as observed in the major season was observed across all sampling period (Table 4.4b).

Table 4.4a Effect of soil type on stem diameter of cowpea in the major season

	Stem diameter (cm)				
Soil type	**3 WAP**	**5 WAP**	**7 WAP**	**9 WAP**	**11 WAP**
Top soil	0.50	0.63	0.71	0.76	0.81
Sub soil	0.40	0.45	0.53	0.59	0.65
Termite soil	0.45	0.56	0.62	0.69	0.75
LSD (0.05)	0.05	0.06	0.07	0.09	0.07
CV (%)	7.00	6.70	6.70	7.30	5.80

WAP= Weeks after planting

Table 4.4b Effect of soil type on stem diameter of cowpea in the minor season

	Stem diameter (cm)				
Soil type	**3 WAP**	**5 WAP**	**7 WAP**	**9 WAP**	**11 WAP**
Top soil	0.30	0.40	0.47	0.50	0.50
Sub soil	0.20	0.22	0.29	0.33	0.34
Termite soil	0.25	0.33	0.38	0.43	0.44
LSD (0.05)	0.05	0.06	0.07	0.09	0.07
CV (%)	12.50	11.60	10.90	11.90	10.00

WAP= Weeks after planting

4.4.3 Effect of soil type on number of leaves of cowpea

The results of the effect of soil type on number of leaves of cowpea in the major and minor seasons are shown in Tables 4.5a and 4.5b respectively. Generally, more leaves were produced in the major season than in the minor season across the soil types. At 3 WAP in the major season, number of leaves of cowpea produced by the top soil (4.1) was similar ($p > 0.05$) to the number produced by the termite mound soil (3.4) but significantly higher ($p < 0.05$) than the number produced by the sub soil (3.3). At 5, 7 and 9 WAP, the top soil produced more leaves than both the sub and termite mound soils. A similar trend as observed in the major season was observed across all sampling period in the minor season (Table 4.5b).

Table 4.5a Effect of soil type on number of leaves of cowpea in the major season

	Number of leaves				
Soil type	**3 WAP**	**5 WAP**	**7 WAP**	**9 WAP**	**11 WAP**
Top soil	4.1	6.6	15.8	19.1	13.1
Sub soil	3.3	5.1	8.9	14.5	9.1
Termite soil	3.4	4.9	11.6	16.9	9.5
LSD (0.05)	0.8	0.8	2.9	5.1	3.4
CV (%)	12.8	7.9	14.0	17.5	18.5

WAP= Weeks after planting

Table 4.5b Effect of soil type on number of leaves of cowpea in the minor season

	Number of leaves				
Soil type	**3 WAP**	**5 WAP**	**7 WAP**	**9 WAP**	**11 WAP**
Top soil	2.1	3.9	11.8	13.8	9.3
Sub soil	1.2	2.1	4.8	9.5	5.3
Termite soil	1.4	2.3	8.1	11.8	5.6
LSD (0.05)	0.8	0.5	3.0	5.1	3.5
CV (%)	29.7	11.3	21.3	25.4	29.8

WAP= Weeks after planting

4.4.4 Effect of soil type on number of flowers of cowpea

Higher number of flowers were observed in the major season (Table 4.ba) compared to the minor season (Table 4.6b) across the soil types. In the major season, the top soil significantly ($p < 0.05$) produced more flowers across all sampling periods. This was followed by the termite mound soil with the sub soil producing the least (Table 4.6a). At 7 and 8 WAP in the minor season, no significant differences ($p > 0.05$) in number of flowers were observed among the soil types. However, at 9 WAP, the top soil significantly ($p < 0.05$) produced higher number of flowers (6.0) than the other soil types (Table 4.6b).

Table 4.6a Effect of soil type on number of flowers of cowpea in the major season

	Number of flowers per plant		
Soil type	**7 WAP**	**8 WAP**	**9 WAP**
Top soil	10	10	12
Sub soil	5	4	4
Termite soil	7	7	7
LSD (0.05)	1.4	2.9	2.5
CV (%)	11.6	24.5	19.5

WAP= Weeks after planting

Table 4.6b Effect of soil type on number of flowers of cowpea in the minor season

	Number of flowers per plant		
Soil type	**7 WAP**	**8 WAP**	**9 WAP**
Top soil	5	7	6
Sub soil	5	5	2
Termite soil	4	5	3
LSD (0.05)	NS	NS	2.0
CV (%)	26.0	28.5	30.8

WAP= Weeks after planting; NS= Not significant

4.4.5 Effect of soil type on number of pods per plant

Results of the effect of soil type on number of pods per plant of cowpea in the major and minor seasons are shown in Tables 4.7a and 4.7b. Number of pods per plant were relatively higher in the major season than in the minor season. At 7 WAP in the major season, the top soil produced more pods per plant (6.0) which was significantly ($p < 0.05$) higher than the sub soil (3.2) but similar ($p > 0.05$) to the number produced by the termite soil (4.6). At weeks 8 and 9 after planting, both the top and termite mound soils produced more pods per plant than the sub soil (Table 4.7a). In the minor season, the top soil significantly ($p < 0.05$) produced more pods per plant (4.2) than the other soil types at 7 WAP. However, at 8 WAP, no significant differences ($p > 0.05$) in number of pods per plant were observed among the soil types. At week 9 after planting, the trend changed where the top soil produced more pods than the termite mound soil which was also higher than the sub soil (Table 4.7b).

Table 4.7a Effect of soil type on mean number of pods per plant of cowpea in the major season

	Number of pods per plant		
Soil type	**7 WAP**	**8 WAP**	**9 WAP**
Top soil	6.0	9.4	11.3
Sub soil	3.2	4.3	4.7
Termite soil	4.6	8.2	8.6
LSD (0.05)	2.1	3.4	2.9
CV (%)	26.1	26.6	20.6

WAP= Weeks after planting

Table 4.7b Effect of soil type on mean number of pods per plant of cowpea in the minor season

	Number of pods per plant		
Soil type	**7 WAP**	**8 WAP**	**9 WAP**
Top soil	4.2	5.4	8.3
Sub soil	0.8	3.3	1.7
Termite soil	1.8	4.2	5.6
LSD (0.05)	1.5	NS	2.9
CV (%)	26.9	25.9	23.5

WAP= Weeks after planting; NS= Not significant

4.4.6 Effect of soil type on yield parameters of cowpea

The results of the effect of soil type on cowpea yield parameters in the major and minor seasons are presented in Tables 4.8a and 4.8b respectively. There were significant ($p < 0.05$) differences in yield among the soil types. Yield parameters were generally higher in the major season compared to the minor season across the soil types. The top soil significantly ($p < 0.05$) had the highest number of pods that were filled among the soil types in both seasons, followed by the termite mound soil while the sub soil had the least. There were no significant differences ($p > 0.05$) in number of pods that were empty among the soil types in both seasons. Pod weight per plant was highest in top soil (64.5 and 57.5 kg/ha in major and minor season respectively) and least in the sub soil (28.0 and 21.0 g in major and minor season respectively). Number of seeds produced per plant were not significantly different ($p > 0.05$) between the top and termite mound soils but were significantly ($p < 0.05$) higher than the number produced in the sub soil in both the major and minor seasons. In the major season, the top soil significantly ($p < 0.05$) produced the highest total grain yield (390.0 kg/ha) which was about 16 % more than the amount produced in the termite mound soil and 63 % more than the amount produced in the sub soil (Table 4.8a). Similarly, in the minor season, the top soil had a grain yield which was more than twice the amount produced in the sub soil (Table 4.8b).

Table 4.8a Effect of soil type on yield of cowpea in the major season

Soil type	Filled pods per plant	Unfilled pods per plant	Pod weight per plant (g)	No of seeds per plant	Total grain yield (kg/ha)
Top soil	49.50	8.00	64.50	401.00	390.00
Sub soil	18.00	13.00	28.00	114.00	239.90
Termite soil	34.50	8.50	52.50	305.00	333.40
LSD (0.05)	7.27	NS	16.98	137.50	46.32
CV (%)	12.40	24.40	20.30	29.10	8.30

NS= Not significant

Table 4.8b Effect of soil type on yield of cowpea in the minor season

Soil type	Filled pods per plant	Unfilled pods per plant	Pod weight per plant (g)	No of seeds per plant	Total grain yield (kg/ha)
Top soil	45.50	10.00	57.50	340.00	305.00
Sub soil	14.00	15.00	21.00	94.00	148.90
Termite soil	28.80	10.50	44.20	291.00	258.10
LSD (0.05)	6.90	NS	16.09	15.20	52.99
CV (%)	13.60	37.70	22.70	36.60	12.90

NS= Not significant

4.5 Relationships among soil properties, growth and yield of cowpea in all seasons

Correlation analyses were done to establish the relationship among soil properties, growth and yield of cowpea (Table 4.9). Soil pH significantly correlated positively with ECEC (r = 0.835), available P (r= 0.736), exchangeable K (r= 0.896), organic matter (r= 0.797) and total N (r = 0.887). Significant positive relationships were observed between organic matter and available P, ECEC, exchangeable K and total N (r = 0.982, 0.767, 0.923 and 0.954 respectively). Soil total N had significant positive relationships with available P (r= 0.919), ECEC (r= 0.863) and exchangeable K (r=0.935). Total grain yield of cowpea correlated positively with organic matter, total N, available P, exchangeable K, ECEC and pH (r= 0.725, 0.793, 0.686, 0.749, 0.646 and 0.740 respectively). There were significant positive relationships between grain yield and plant height and stem girth (r= 0.936 and 0.77). Number of flowers had significant correlation with number of pods and grain yield (r= 0.662 and 0.676).

Table 4.9 Relationships among soils properties, growth and yield of cowpea

	Avai. P	ECEC	Exch. K	Flower number	Grain yield	Organic matter	Plant height	Pod number	Pod weight	Seed number	Stem girth	Total N	pH
Avai. P	-												
ECEC	0.694*	-											
Exch. K	0.863*	0.864*	-										
Flower number	0.678*	0.630*	0.576*	-									
Grain yield	0.686*	0.646*	0.749*	0.676*	-								
Organic matter	0.982*	0.767*	0.923*	0.692*	0.725*	-							
Plant height	0.654*	0.571*	0.691*	0.733*	0.936*	0.684*	-						
Pod number	0.489*	0.581*	0.580*	0.662*	0.931*	0.547*	0.906*	-					
Pod weight	0.679*	0.561*	0.773*	0.559*	0.926*	0.714*	0.918*	0.815*	-				
Seed number	0.632*	0.490*	0.711*	0.511*	0.896*	0.652*	0.860*	0.791*	0.970*	-			
Stem girth	0.443	0.586*	0.481*	0.721*	0.77*	0.472*	0.789*	0.839*	0.566*	0.503*	-		
Total N	0.919*	0.863*	0.935*	0.711*	0.793*	0.954*	0.721*	0.622*	0.757*	0.681*	0.55*	-	
pH	0.736*	0.835*	0.896*	0.618*	0.740*	0.797*	0.690*	0.607*	0.800*	0.752*	0.423	0.887*	-

*= significant at 5% level of probability

CHAPTER FIVE

5.0 DISCUSSION

5.1 Chemical characteristics of top, sub and termite mound soils

Trends in the results of soil types both in major and the minor seasons showed a similar pattern. Soil pH was relatively higher in the major season compared to the minor; this agrees with studies of Olojugba (2018). In that study, it was reported that in the soils of a Tropical Southern Humid Rainforest Ecosystem in Nigeria, a similar pattern as in this study was observed for pH. Termite mounds in both seasons have relatively higher pH than sub soil. This is because, according to studies of Chisanga *et al*. (2020), clay content in termite mound is about 20% higher and this having larger adsorption sites for cations such as calcium ion, magnesium ion and potassium which might have increased the pH and thus prevented soil acidity. The increased in pH occurs when cations are absorbed, they replace hydrogen ions in the soil solutions giving rise to high pH. Similarly, due to the activities of termites, their death and decay increase organic matter content in these sites and serves as a buffer to the soil pH change. The organic matter provides much of the pH buffering capacity of soils through its high cation exchange capacity and acid and base functional groups. The high cation exchange capacity of organic matter means more reserve and exchangeable acidity must be neutralized. The pH range of the top soil and the termite mound soil in this experiment were best for cowpea production as cowpea performs best within a pH range of 5.5 to 6.5 (Davis et al., 2003).

Soil Organic Carbon (SOC), content between the two seasons saw a similar trend but the major season saw a relatively higher amount. According to studies of Chen (2020), rainfall affects available organic matter content in the soil, this is because, water helps in the breakdown of organic matter to form carbonic acid and similarly water also helps in the decomposition of organic matter. It has been established that available moisture or water is also important to the activities of microorganisms that help in the breakdown of these substances. Both Figures 4.2a and 4.2b showed high amount of SOC in top soil compared to sub and termite mound soils. The lower SOC in sub and termite soils could be as a result of low organic matter content in these soils. Chisato (2013) reported that termite mounds are generally known for lower vegetations hence reduced available organic content as compared to the top soil. Similarly in the sub soil, there is higher compaction and less activities of microorganism which translates into lower SOC compared to top soil (Chisato, 2013). Soil organic carbon in the top soil was high which might have contributed to the high yield of cowpea, since higher soil organic carbon promotes good soil structure which improves soil aeration and water drainage and retention. This according to Issoufou et al. (2019) reduces the risk of nutrient leaching and promotes nutrient holding capacity of the soil.

With regards to soil total nitrogen amongst the three soil types, the major and minor seasons revealed similar graphs. Once again, higher values of N were recorded in the major season than in the minor season, this agrees with studies of Gonzalez – Padraza and Dezzeo (2014), where it was reported that higher precipitation positively affects higher nitrogen content values. Both figures (4.3a & b) showed decreasing order of nitrogen content from top soil, termite mound and sub soil. This is because higher organic content causes increase in higher nitrogen content and nitrogen in soil decreases along depth. As stated by Chisato (2013), termite mounds generally have lesser vegetation compared to adjacent soils which causes the reduced availability of nitrogen as compared to top soil.

Soil available P in the soils also showed similar pattern in both seasons. Major season values were higher due to increased precipitation (Chen, 2020). This is because soil nutrients dissolution is largely affected by available moisture in the soil at a point in time (Xue *et al*., 2017). Similar trends of available P were recorded just as that of N. The top soil, due to higher biomass content, recorded highest, followed by the termite mound and then sub soil. The termite mound due to relatively higher microbial activities recorded higher P values than the sub soil which is relatively compacted with lesser activities of microbes and low organic matter content (Chisanga *et al*., 2020).

Exchangeable cations, exchangeable acidity, TEB, ECEC and base saturation of the soil sources were similar in both seasons. With a P value less than 0.05, Ca^{2+} and K^{+} were higher in top soil as well as termite mound than in sub soil. Study of Ogeleka *et al*. (2017), indicated that there are lower levels of exchangeable cations in areas of lower organic matter and water. This is evident in this study as generally, the major season recorded higher values than the minor and also the top soil and termite mound accumulated significant differences compared to the sub soils. Generally, TEB, ECEC and base saturations, were higher in the top soil than the termite mound and then sub soils for both major and minor seasons which contributed to the high yields of cowpea in the top soil as high ECEC in the soil helps to retain more nutrients in the soil. According to Luo *et al*. (2019), these parameters are influenced by other soil properties such as organic matter and moisture. The presence of higher organic matter causes a rise in the concentrations of these soil parameters. As stated above in the studies of Chisato (2013), sub soils generally have lower microbial presence, low vegetation and higher compaction than the other types of soil employed in this study. Exchangeable acidity (EA) in both seasons was higher in sub soil than top and termite mound soils, this can be attributed to cation uptake by plant roots that fall in those sections of the profile (Tang, 2004). The major season recorded 0.68 Cmol/kg soil and the minor recorded 0.73 Cmol/kg soil, these two values were the highest recorded (EA) amongst the top soil, sub soil and termite mound soils. The sub soil recording the highest exchangeable acidity in both seasons could have contributed to the low yield of cowpea in the sub soil, since high exchangeable acidity has negative effects on soil condition and many processes in the soil including phosphorus deficiency in plants and toxic levels of manganese and iron.

5.2 Hydro-physical characteristics of top, sub and termite soils

Bulk density increases along depth with sub soil recording higher values for both minor and major seasons. Study of Twum and Nii-Annang (2015) amongst other studies have established that bulk density generally increases with depth due to lower organic matter of lower layers of the soil. This trend was evident in this study as sub soil recorded higher bulk density compared to top soil and termite mound soils which have organic and microbial activities. It is seen that the top soil recorded lower bulk density values than the termite mound because as discussed in the earlier paragraphs, termite mounds have very low or no vegetation compared to its adjacent top soil plots (Chisato, 2013). This rendered the bulk density values in the termite mound soils to be higher than the top soil due to higher organic matter and microbial actions in top soil. This transcended into values for moisture content and porosity (Chisato, 2013; Twum and Nii-Annang, 2015). Soil physical characteristics are known to have major influence on crop yield and have been reported by other researchers. For instance, a study conducted by Tueche (2014) in Cameroon revealed that soil physical properties can have positive and negative effects on yield of crops. According to the authors, yield of maize was higher in soils with lower soil bulk density than soil with higher bulk density.

This shows that an increase in bulk density or soil compaction would actually have an adverse effect on yield (Lipiec *et al*., 1991). It has also been established that increase in soil bulk density (compaction) decreases porosity which consequently reduces the water holding capacity of the soil. This was shown in this study where the top soil which had lower bulk density had higher soil porosity and moisture content (Table 4.3a and 4.3b) which translated into higher cowpea yield (Table 4.9a and 4.9b). Results of the study showed that the amount of clay fractions were higher than silts fraction in the termite mound soil than the top soil and sub soil. (Tables 4.3a and 4.3b). The protective action by clay against organic matter degradation through the formation of complexes between metal ions associated with large clay surfaces and high CEC explains the effect of soil texture on organic matter decomposition (Giller *et al.,* 1997). Total porosity is also another important soil physical property which can affect plant growth both directly and indirectly. Porosity also modifies bulk density as well as water transmission through the soil which have an indirect effect on plant growth. The results of the relationships of soil total porosity with soil types in (Table 4.3a) shows that the top soil recorded the highest total porosity. The implication is that, increasing porosity enhances the growth of and yield of cowpea.

Major source of water is rainfall and irrigation. Rainfall is affected by seasonal variation. Major season rain occurs between March and July and the minor season is between September and November. An amount of moisture in the soil always determines growth and yield of crops. Soil moisture content is crucial for the growth and development of plants. It influences the dissolution, absorption and transportation of plant nutrients as well as biological activities.

According to Micheni *et al.* (2004) the soil organic matter plays an important role in maintaining physical, chemical and biological properties of the soil, and therefore the crop productivity and yield.

5.3 Effects of soil types on growth and yield of cowpea

With regards to the effect of soil types on the height of cowpea, after 11 weeks of planting (WAP), the height of cowpea in top soil was 25.33cm, and that of sub soil was 18.43cm. This is consistent with findings of Liu *et al*. (2012), where they identified important soil nutrients in the top soil and absent in the sub soil. Due to the presence of high organic matter levels which contain higher levels of N, P and K as revealed in this study, plants are generally able to do better in the top soil than in the sub soil. Results of cowpea height was significantly different in top soil from termite mounds. This is because, though termite mound soils have high microbial activities hence better than sub soil, there is high vegetative and humus content in top soils. This feature discussed in the previous paragraphs renders top soil a better alternative to termite mounds which was better than sub soils.

Results in this section followed a similar pattern for heights, stem girth and number of flowers. Number of flowers was 12 and 6 per plant for top soils in major and minor season respectively. Considering the seasons of planting, the major season caused better growth results compared to the minor. This can be attributed to the presence of higher available moisture / water in the soils. This will make available nutrients through dissolution and also reduce evapotranspiration to enhance growth. The number of leaves obtained in this study followed the general perception and studies carried out where top soils and termite mounds gave higher results (Liu *et al*., 2012). The top soil in this study produced cowpea with the highest number of leaves.

The effect of soils types on mean number of pods per plant followed similar pattern as discussed above, this recorded 11.3 in the major season and 8.3 in the minor season for top soil. Yield trends similarly followed the already established pattern with 390 kg/ha highest for topsoil and 239.90 kg/ha for sub soil being the least in the major season. In the lean season, top soil recorded 305.00 kg/ha and 148.90 kg/ha for sub soils. These results follow trends of already carried out studies where top soil gave best yield trends (Nathan, 2011; Liu *et al*., 2012). Per pod grain weight, top soil produced the highest values of 64.5g and 57.5g for major and minor seasons while the least values were recorded in sub soil (28.0g and 21.0g respectively).

5.4 Relationships amongst soil properties, growth and yield of cowpea

There were positive correlation relationships between ECEC and grain yield ($r = 0.646$), this possibly explains the uptake of cations by the plant which helps to enhance yield (Liu *et al*., 2012). Cation uptake helps the soil to hold onto essential nutrients and makes it available for plants' growth. Similarly, there was a positive correlation between organic matter and ECEC, this implicates the addition of cations from the organic matter into the soil. pH had a positive correlation with ECEC ($r = 0.835$). This agrees with the studies of Chisanaga *et al*. (2020), pH increases as more cations are added into the soil to reduce its acidity. There was a strong positive correlation ($r = 0.954$) between organic matter and total N, this is because the breakdown of organic matter releases nitrogen for plant uptake (Chen, 2020). Most of the parameters had positive correlations and this is evident in the study as most of the results seem to agree with already carried out studies in other parts of the world outside Ghana.

5.5 Nodulation assessment

Nodulation assessment was done for all treatments with only two plants having one nodule in 2018 minor season. Worse trend was observed for 2019 major season with no nodule. Literature confirmed that nodulation failure is as a result of absence of proper nodulating bacteria. The plant will not have nodules and it will depend on soil available nitrogen for its growth. Failure to nodulate could be as a result of excessive moisture in the soil which was not the case in the study, new cowpea fields, due to low bacteria populations in the soil, fields containing high levels of residual soil nitrogen from a previous forage legume or manure application, coarse-textured soils due to inadequate moisture levels to sustain bacteria, flooded or saturated soil conditions lasting seven days or more due to oxygen deprivation which was also not the case of this study. Soil pH below 5.7 or above 7.3. Compacted soils due to reduced oxygen availability (Torabian et al., 2019). Poor nodulation could have contributed to the relatively poor grain yield obtained in this study. The poor nodulation suggests that in future if cowpea is to be planted on such or similar soils there will be the need to inoculate the seed with rhizobium bacteria to ensure better nodulation.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Generally, there seemed to be an established trend of physico-chemical properties in the soil types. Important soil nutrients such as N, P and K, organic matter and pH all were high in top soils, followed by termite mound and then the sub soils. Physical properties such as bulk density, porosity and moisture content were also aligned in a similar trend. Hydrological properties such as moisture content was more pronounced in top soils with sub soils having the least. On the effect of the soil types on growth parameters and yield of cowpea, top soil recorded higher values compared to the other two soil types. Regardless of the season in which planting was done, this trend remained same. Yield results revealed the best soil type as the top soil, followed by the termite mound soil. Soil pH correlated positively with ECEC, available P, exchangeable K, organic matter and total N. Total grain yield of cowpea correlated positively with organic matter, total N, available P, exchangeable K, ECEC and pH (r= 0.725, 0.793, 0.686, 0.749, 0.646 and 0.740 respectively)

6.2 Recommendations

Farmers should mix their top soil with quantities of the termite mound soil to increase the yield of cowpea in nurseries. It is recommended that in further work treatments should be mixed with soil amendments such as poultry droppings to increase growth and yield of cowpea. The study should be repeated and replicated on the field as done in other countries for better understanding of differences in nutrient concentration in top and termite mound soils.

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