UNIVERSITY OF EDUCATION WINNEBA

TEMPORAL VARIABILITY OF TREE LITTER FALL, SOIL CARBON STOCKS AND HYDROLOGY OF SOILS UNDER DIFFERENT AGRICULTURAL LAND USES

BENETTE YAW OSEI

DOCTOR OF PHILOSOPHY

2022

UNIVERSITY OF EDUCATION WINNEBA

COLLEGE OF AGRICULTURE EDUCATION

MAMPONG-ASHANTI

TEMPORAL VARIABILITY OF TREE LITTER FALL, SOIL CARBON STOCKS AND HYDROLOGY OF SOILS UNDER DIFFERENT AGRICULTURAL LAND USES

BENETTE YAW OSEI

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 THE DEGREE OF

DOCTOR OF PHILOSOPHY

(SOIL SCIENCE)

IN THE UNIVERSITY OF EDUCATION, WINNEBA

JUNE, 2022

DECLARATION

STUDENT'S DECLARATION

I, Benette Yaw Osei declare that this dissertation, **Temporal Variability of Tree Litter Fall, Soil Carbon Stocks and Hydrology of Soils under Different Agricultural Land Uses in the Transitional Agro-Ecological Zone of Ghana,** with the exception of quotations and references contained in published works which have all been identified and acknowledged, is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

SIGNATURE……………………………………
DATE…………………………………………...

SUPERVISORS' DECLARATION

We, hereby declare that the preparation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

PROF. KOFI AGYARKO (Principal Supervisor)

Signature: …………………………………….

Date: ………………………………………….

PROF. GODFRED DARKO (Co-Supervisor)

Signature: …………………………………….

Date: ………………………………………….

PROF. RICHARD KOTEI (Co-Supervisor)

Signature: …………………………………….

Date: ………………………………………….

DEDICATION

This work is dedicated to my parents, Benedicta Ama Dufie Appiah and Philip Kwadwo Nyantakyi, My wife Jenifer Iries Mensah, my sons, Philip Kwadwo Nyantakyi Junior, Adombi Kofi Osei-Obrempong and Kwame Ofori Osei-Okatakyie and my loving brother Douglas Kwame Gyambibi.

ACKNOWLEDGEMENTS

My profound gratitude is to the Almighty God for His guidance and protection throughout the course. "If I have come this far, it is because I have stood on the shoulders of giants or because I try to work harder”. I am also grateful to my Principal Supervisor, Prof. Kofi Agyarko and Co-Supervisors Prof. Godfred Darko, (Head of Department; Chemistry, Kwame Nkrumah University of Science and Technology) and Dr. Richard Kotei (Head of Department; Agricultural Mechanization and Engineering Education) who resourcefully and untiringly supervised this work by giving their priceless guidance and constructive criticisms. Their directives, correction and valuable suggestions especially during the write-up were particularly helpful.

I am also indebted to Mr. Emmanuel Aseidu and Prof. Mensah Bonsu for their mentorship. To Prof. Mrs Margaret Essilfi (Head of Department; Crop and Soil Sciences Education, AAMUSTED), the late Prof. S. Y. Annor, Prof. Kagya-Agyemang (immediate past Principal-CAGRIC, UEW and AAMUSTED), Prof. Harrison Dapaah (immediate past Vice-Chancellor, University of Energy and Natural Resources), Rev. J.W. Tevor, Rosemary Adu-Poku and Rev. Nkrumah Hope, I am grateful for the encouragement and coaching. Thanks to Dr. Henry Oppong Tuffour (Crop and Soil Science Department, KNUST), Awudu (Soil Science Lab, KNUST), Dr. Opoku Gyamfi (Chemistry Department, AAMUSTED), Ebenezer Bediako, Jolly Jakper, Rebecca Smith Avinu (Secretary Estates: AAMUSTED, Mampong), Kofi Amponsah (Farm Manager, AAMUSTED-Mampong), Alex Otabil (Assistant registrar, AAMUSTED-Mampong), Mr. Kwabena Amoako, Benjamin Nkatiah and following technicians, Mr. Enos Kwame Adepa and Augustus Akwasi Antiedu for their suggestions and support in terms of equipment and technical advice.

Dr. Kwabena Attakorah (UENR), Dr. Kwabena Kyere (UEW), Dr. Dr. Eric Opoku Mensah (PGRRI-CSIR) and Dr. Esther Fobi Donkor (UENR), I am grateful and indebted to you for your support, you virtually dragged me through this course.

To my Abonkosu D/A basic school family, where it all started. I am grateful to Joycelyn Inkoom, Eunice Owusu, Nana Yaw Sekyere, Cecilia, Josephine Sanyor, Margaret Marfo, Clement Osei-Owusu, Agyemang, Antwi Yeboah, Philomina Danquah, Gloria Achiaa, Sarfo Abraham and Rtd. Justice Richard Aboagye for the support and help during the data collection and processing.

My sincere gratitude goes to Martha Agyiri, Rev. William Agyei Brantuo and their family for their contribution to the successful completion of this work. I couldn't have come this far without your support both physically and spiritually. To my Head of Department (Science) Kofi Mensah, thanks for the time off that you gave me to complete this work. Not forgetting the encouragement from my colleagues from the Presbyterian College of Education, Akropong, Ahmed Asmau, Addo Novice, Richmond Blay, Emmauel Appawu, Nathaniel Atikumi, Maureen Nkansah, Georgina Fianu, Anita Brako, Emmanuel Owusu, Emmanuel Eshun, Benjamin Lifeson, Isaac Indome (now at UEW) and Valentine Avotre.

I also wish to thank the following friends who have played vital roles in the completion of this PhD work: Eric Yeboah Osei, Fredick Osei-Frimpong Jnr, Ernest Allotey, Emmanuel Adzraku, Dr. Emmanuel Otchere-Darko, Theresa Fripomaa, Lawyer George Afriyie Asare, Daniel Owusu Nsafoah, Levis Karley (Aministrator, Asonomanso Government Hospital) Freda Ama Opoku Doudu, Mabel Doe (May dear), Lois, Edward Osei-Frimpong and Doris Osei (Bijay Pharmacy).

TABLE OF CONTENT

Contents

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The research was conducted at the crop plantations of Akenten Appiah Minkah University of Skill training and Entreprenuarial Development (AMUSTED – Mampong in the forest-savannah transition agro-ecological zone of Ghana. The objective of the research was to assess the seasonal variations in litter fall, soil carbon accumulation and hydro-physical properties of soils under different agricultural land use. The experiment was a 5 × 6 factorial, laid in a randomized complete block design, with 5 different land uses and 6 distinct seasons. The land uses were forest stand, cocoa plantation, coffee plantation, cashew plantation and mango plantation while the seasons were dry season 2016, major rainy 2016, minor rainy 2016, dry season 2017, major rainy 2017 and minor rainy 2017. A field test was conducted to measure soil bulk density, volumetric moisture content, total porosity, air-filled porosity, degree of saturation and aggregate stability of soils under the different land uses. Cumulative infiltration, infiltration rate, sorptivity, steady state infiltrability and saturated hydraulic conductivity were also evaluated. For carbon accumulation, quantity of litter fall, soc, soil carbon stocks and soil carbon sequestration were measured. A laboratory analysis was carried out to measure total nitrogen, phosphorus, pH, exchangeable bases like calcium, magnesium, potassium. Microbial biomass (C_{mic}, N_{mic} and P_{mic}), microbial quotient (qC_{mic}, qN_{mic} and qP_{mic}) and microbial biomass ratios (C_{mic}/N_{mic}, C_{mic}/P_{mic} and N_{mic}/P_{mic}) were all measured. The bulk densities of soils under the different land uses were significantly different ($p<0.05$) from each other, in the order mango > cashew > coffee > cocoa > forest. Both the soil gravimetric and volumetric moisture content differed significantly among land uses, with cashew and coffee recording the highest and lowest values in both instances, respectively. Significant ($p<0.05$) seasonal variations in soil moisture were observed in the order MNRS2017 > MNRS2016 > MRS2017 > MRS2016 >

DS2017 > DS2016. The study showed, significant difference in total porosity, air-filled porosity and degree of saturation of the different land uses and seasonal variations, with aeration decreasing with increased rainfall amount. Aggregate stability was significantly different among the different land uses and season. Aggregate stability gradually improved over seasons by 1.5 % to 11.1 % from season DS2016 to MNRS2017. Hydrological and hydraulic properties of soils under the different land uses were significantly different from each other. Seasonal cumulative infiltration amount and hydraulic conductivity of soils ranged from and 90.2 to 154.1 mm and 0.036 to 0.077 mm s^{-1}, respectively. Litter fall significantly differed among the different land uses, forest stand (3.28 t/ha) and mango plantation (2.27 t/ha) recorded the highest and lowest. Significant seasonal variations of litter fall were recorded, with DS2017 (4.06 t/ha) and MRS2016 (1.80 t/ha) recording the highest and lowest, respectively. Soil carbon stocks and soil carbon sequestration was highest (48.04 Mg C/ha and 179.2 CO_2 Mg/ha) and lowest (45.7 Mg C/ha and 167.7 CO_2 Mg/ha) in mango plantation and forest stand, respectively. Total nitrogen, available phosphorus, potassium, magnesium, calcium and pH were significantly different among the different land uses. Soil microbial biomass (C_{mic}, N_{mic} and P_{mic}) which ranged from 151.3 to 323.8 mg/kg, 22.28 to 47.32 mg/kg and 7.89 to 25.5 mg/kg, respectively differed significantly among the different land uses and seasons. Microbial quotients (qCmic, qNmc and qPmic) decreased in the dry seasons (DS2016 and DS2017), while it was highest in the minor rainy reasons (MNRS2016 and MNRS2017). It is recommended that, mango, cashew, cocoa and coffee could be used to store and sequester as much carbon as the forest when they are properly managed. Coffee > cocoa > cashew > mango improved soil hydrological and hydraulic properties in this order of efficiency.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Over the last decade, the relative size of the agriculture sector in Ghana has more than halved, amounting to 15.3 % of nominal GDP as of the second quarter of 2019, down from 31.8 % in 2009. Nonetheless, the sector retains its strategic importance as a major employer, comprising 44.7 % of the labour force (MOFA, 2020). Given agriculture's crucial role in providing jobs for Ghana's growing population, the government has embarked on significant modernisation efforts since 2017, chief among them is the Planting for Food and Jobs initiative. This was followed in 2018 by the umbrella programme, investing for Food and Jobs, which is focused on agriculture, food security and rural development (Bruzzone, 2020).

While cocoa remains the dominant source of agricultural export earnings, a number of other tree crops, including cashew, coffee, coconut, oil palm, mango, rubber and shea nut, have seen promising harvests over the past few years. In an effort to capitalise on this potential to diversify revenue, the government initiated the Planting for Export and Rural Development (PERD) programme in April 2019. Once the programme was implemented and related value chains put in place, it was expected that each of these tree crops could provide up to $2 billion of annual export earnings (MOFA, 2020). Through intensification of agricultural activities, significant growth was recorded with a real agricultural GDP increasing from 2.9% in 2016 to 6.1% in 2017, 4.8% in 2018 and a projected 6.9 % in 2019 (MOFA, 2020).

To further strengthen the institutional structures of the industry, in 2019 the Tree Crop Development Authority was established. It was set to distribute a total of 11.74 million seedlings comprising 5 million cashew, 100,000 coffee, 40,000 coconut, 5 million oil palm, 100,000 mango and 1.5 million rubber seedlings in the 2019. This allowed for the establishment of some 88,918 ha of plantations across 212 districts by the end of 2020. As at September 2019, 91,292 farmers from 4,777 communities in 199 districts and 12 regions had received tree crop seedlings through the initiative (MOFA, 2020).

Almost half of the total soil organic carbon in terrestrial ecosystems is stored in forest soils. Therefore, the conversion of primary forests to Agricultural lands generally reduces soil carbon stocks. By altering rates of input or release of soil organic carbon from soils, forest management activities can influence soil carbon stocks in forests (Mayer *et al.*, 2020). According to Yang *et al.* (2003), forest litter acts as an input-output system of nutrients and the rates at which forest litter falls contribute to the regulation of nutrient cycling, fertility sustenance and primary productivity in forest and tree-based ecosystems. Litter fall and litter decomposition and subsequent nutrient release represent major biological pathways for element transfer from vegetation to soils. These processes play important roles in regulating nutrient cycling and maintaining soil fertility in forest and agroecosystems (Ranger *et al.*, 2003).

Soil is an important component of ecosystems and supports plant growth by regulating nutrients, energy, and water cyclying process. It also plays a major role in the carbon cycle among the atmosphere, land, and ocean (Babur and Dindaroglu, 2020).

The dynamics of organic carbon storage in agricultural soils is gaining increasing importance because of its impacts on climate change and benefits for crop productivity. Good farming practices have the potential to make a net sink for carbon by attenuating carbon dioxide (CO_2) load in the atmosphere and improving soil fertility and hence productivity (Naik, Maurya and Bhatt, 2016).

In early May 2013, global atmospheric concentration of carbon dioxide (CO_2) reached 400 ppm (Ralph, 2013). Africa accounts for 17% of global CO_2 emissions from changes in land use patterns and management patterns (Daouda *et al*., 2017). Changes in land use patterns contribute up to 48% to Africa's total carbon emissions. This level has probably not been achieved in the last 20 million years and continues to increase at a rate of about 2 ppm per year (IPCC, 2001).

1.2 Problem Statement

There is a general increase in population across the world, hence the need to produce more food and raw materials to mitigate food shortage and improve food security while providing adequate raw materials for industries (FAO, 2020). As the human population grows, notably in the tropics and subtropics (where many rural people live in poverty), the difficulties of increasing food production also increase. In Sub Sahara Africa, average crop yields are in gradual decline. In spite of improved plant breeding, the rates of rise in potential yield are slowing down (FAO, 2020).

In other to produce more food to meet the needs of the growing population, forests are being converted to agricultural lands while the already existing agricultural lands face degradation because of intensification of agriculture and the inherent low fertility of our soils (MOFA, 2013). As good land for the lateral expansion of agriculture becomes scarcer, there is increasing need to intensify land use without causing a decline in productive potential. Market-driven rapid intensification is often a major cause of cropland area expansion at the expense of deforestation (Byerlee *et al.,* 2014). Moreover, it is widely understood that intensive agriculture can negatively impact ecosystems by affecting the rural landscape dynamics, soil resources and water quality. This can result in the loss of carbon sequestration and biodiversity, which are critical global public goods (Laurance *et al.,* 2014). Secondly, farmers are aware that, land cleared from previously undisturbed vegetation provides “free fertility” from which the first crops benefit. But they also know that after a few seasons, productivity declines and that part of this decline is associated with the degradation of soil physical and chemical conditions. It is less commonly recognized that, this soil damage and the loss of organic matter results in decreased soil infiltration, increased surface runoff and reduced soil moisture status.

There is little knowledge on the effect of seasons and different land uses on soil hydraulic and hydrological properties. Farms created at the expense of forests will still result in significant disruption of soil physical and hydrological properties. Conversion of forest to other agricultural land uses and tree-based cropping systems like cocoa, coffee, cashew and mango will likely result in degradation of soil physical, chemical and hydraulic properties. Despite their significance, soil hydrological and hydraulic properties are poorly assessed under different land uses in Ghana.

There is inadequate knowledge on the influence of litter fall from tree crops on soil hydro-physical properties as most studies are concentrated on its effect on soil chemical properties and fertility. Despite many studies carried out on litter fall and decomposition dynamics, in both tropical and temperate forests (Isaac *et al*., 2005), few attempts have been made to assess the influence of litter fall on soil hydro-physical properties under cocoa, coffee, cashew and mango.

In Ghana, there is inadequate data on temporal changes in soil organic carbon and soil microbial biomass due to tree crops and the seasonal effect on them under different land use and managements. Most studies are on soil carbon stocks and soil microbial biomass in agro-forestry and there is little to no information on Mango, cashew and coffee plantations. Although some works are done on cocoa often it is done on farms with tree shades. Despite the attention given to soil organic carbon (SOC), current knowledge remains limited regarding SOC baselines and changes, the detection of vulnerable hot spots for SOC losses and opportunities for SOC gains under both climate and land management changes (Babur, 2018).

Changing climate is affecting the suitability of certain cash crop production in certain areas of the country. Thus, areas that were initially not suitable for some crops are now becoming suitable, while areas that were suitable are becoming unsuitable. This is because there is too little understanding of some key ecological and ever-changing linkages. For example, it is the complex set of interactions among climate, vegetation, soils, water and landscape that results in the crop yields each season. (Laderach *et al*., 2011).

1.3 Justification

It is important to understand the effects of changes in land use systems and agricultural practices on SOC when assessing their potential environmental impact. It is widely acknowledged that shifting from natural to managed ecosystems, such as arable cropping, results in a loss of SOC (Powlson *et al*., 2011). Identifying how different agricultural management practices or changes in land use create SOC sinks (accumulating additional C), act as C sources (emitting C) or maintain stocks at current levels is imperative in identifying effective strategies for land-based climate change mitigation.

Soil hydraulic properties such as sorptivity and hydraulic conductivity are among the most important parameters that determine soil quality and its capability to serve the ecosystem. Land use can significantly influence soil properties including its hydraulic conditions. However, additional factors, such as changes in temperature and precipitation can further influence the land use effects on soil hydraulic properties. In order to develop possible adaptation measures and mitigate any negative effects of land use and climatic changes, it is important to study the impact of land use and changes in land use on soil hydraulic properties (Horel *et al.,* 2015). Water and nutrients are essential for plant production and soil functioning; accordingly, it is important to know the impact of various land use types and soil management systems on water and nutrient transport within the soil matrix. Moreover, in agricultural systems, the soil plant available water can affect cultivation methods and economic considerations such as use of an irrigation system. Therefore, understanding the soil hydraulic properties and their changes over time under specific land use and management practices may influence future decision making in both agricultural and environmental sectors (Horel *et al.,* 2015).

Assefa *et al.* (2020) reported that knowledge of the soil water content variations in different agricultural land uses and in different seasons of the year is important to several fields of study. Also, according to Feltrin *et al.* (2013), knowledge of how this variation in soil water content behaves is important for the adoption of adequate techniques for soil management and conservation.

Soil organic matter (SOM) increases soil structural stability and resistance to rainfall impact; rate of infiltration and fauna activities by binding soil aggregates together (Bationo *et al.* 2007) and 58 % of soil organic matter is made up of SOC (National Land and Water Resources Audit, 2008). This calls for the assessment of SOC under different land use and seasons, especially as it is affected by the conversion of forest to agricultural land use. SOC determined in the selected land use and seasons will inform researchers and farmers on a win-win agricultural land use (Bessah, 2014).

The availability of information on effect of land use change and seasons on soil organic carbon, soil carbon stock and soil carbon sequestration will immensely contribute towards the development of appropriate adaptation measures to climate change and hence impact positively on socio-economic development of affected communities (Dowuona and Adjetey, 2010).

Preservation of soil organic carbon (SOC) requires knowledge of the quantity and quality of both the SOC content and SOC-decomposing microbial community, (Woloszczyka *et al.*, 2020). Since soil functioning and sustaining soil fertility is governed largely by the decomposition activity of the microflora, there is, particularly, a need for microbial-based indicators (Anderson, 2003).

With the assumption that tree crops mimic forest stands, it is imperative to understand their (cocoa, coffee, cashew and mango land use system) contributions to carbon storage, soil and water conservation and thereby to climate change mitigation.

1.4 Objectives

1.4.1 Main objective

Assess the seasonal variations of litter fall, soil carbon accumulation, microbial biomass and hydro-physical properties of soils under different tree crop plantation land uses.

1.4.2 Specific objectives

1. Compare the soil physical properties under the different land uses (forest stand, cocoa, coffee, cashew, mango plantations) and seasons
2. Evaluate the influence of seasons and land uses on hydrological properties of soils under forest stand, cocoa, coffee, cashew, mango plantations.
3. Determine the effects of seasons and land uses on litter fall, some soil chemical properties and carbon dynamics of soils under forest stand, cocoa, coffee, cashew, mango plantations.
4. Assess the relationship between seasonal changes in soil carbon stock, soil microbial parameters and soil hydro-physical properties

1.5 Hypothesis

Seasonal variations and land use significantly influence soil carbon dynamics and soil hydro-physical properties of soils under different agricultural land uses.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cocoa (*Theobroma cacao)*

The cocoa tree known as *Theobroma Cacao* belongs to the family stericuliniacea. Cocoa has its gene center in the upper Amazon region of South America from where it spread to different parts of the world (Osun, 2001).

Cacao trees are grown for cocoa production on an area of over 10 million hectares (ha) in tropical regions throughout the world (FAOSTAT, 2016). Eighty-three percent of cocoa is currently produced in Africa with Asia/Oceania and the Americas producing the remainder (FAOSTAT, 2016). There are approximately 5–6 million cocoa farmers worldwide, growing cacao on typically small (less than 5 ha) family-run farms (World Cocoa Foundation, 2014).

2.1.1 History of cocoa production in Ghana

Cocoa, an important commercial crop of the equatorial region is planted widely across areas bordering the Gulf of Guinea in West Africa, which includes Ghana, Cote D'Ivoire, Nigeria, Liberia, Sierra Leone, Togo and Dahomey (Kishore, 2010).

Among the perennial tree crops, cocoa sector is of particular interest for some parts of West Africa and for the global chocolate industry (Yahaya *et al.,* 2015). In Africa, cocoa production is dominated by four West-African countries. Côte d'Ivoire and Ghana produce approximately 41 percent and 17 percent of the world output respectively. The other two important producers are Cameroon and Nigeria each contributing approximately five percent of the world cocoa production (Binam *et al*, 2008). In most cocoa-producing households, cocoa accounts for over 67 percent of household income (Kolavalli and Vigneri, 2011).

Ghana, formally known as Gold Coast was officially introduced to cocoa by Tetteh Quarshie, after a successful journey from Fernando Po in the Seychelles Island in 1879. However, before Tetteh Quarshie, the Dutch and the Basel Missionaries were the first to plant cocoa in Ghana (Mossu, 1992). Tetteh Quarshie cultivated the beans on his farm in Ghana and was able to grow several seedlings. Growth in cocoa production, especially westwards is somewhat due to migration from the Akwapim Ridge and the Accra plains. Further spread of cocoa in the country was accelerated by the allocation of scattered parcels of forest to the extended families for food and Cocoa cultivation (Mossu, 1992). Since then, Cocoa production has become the main cash crop grown in six out of the then ten regions in Ghana.

Cocoa is cultivated in the forest regions of Ghana where an estimated area of 1.45 million hectares of forest land has been displaced (Anim-Kwapong and Frimpong, 2005). Different production systems are used for cocoa, the most common being monoculture with occasional shade trees (Alfaro-Flores, Morales-Belpaire and Schneider, 2015).

2.1 Influence of Cocoa production on the environment

Essentially, cocoa expansion in Ghana has been closely linked to deforestation (Gockowski, 2011). One option to redress deforestation and create a carbon sink is to encourage the establishment of tree-crop farming or agroforestry systems (Oke and Olatiilu, 2011). Mohammed *et al.* (2016) reported that understanding the effects of land use/land cover changes on ecosystem functions is often inferred from changes in soil organic carbon.

Again, study of the carbon stock in terrestrial ecosystems in the context of climate change has been done on many forest species in many regions. In Cameroon for example, studies have revealed that tree-based systems such as cashew and cocoa agroforests leads to carbon sequestration that are than double of what was observed in the traditional fallows. Thus, the conversion of one hectare of short-term cocoa-based agroforestry fallow could reach 72 tons of carbon from 35tons of carbon from traditional fallows (Durot, 2013).

2.2 Coffee (Coffea *spp*)

The active cultivation of coffee started in Ghana in the mid-eighteenth century when the early missionaries settled in Ghana. It is mostly cultivated by smallholder farmers and in a few plantations scattered in the cocoa growing regions of Ghana (MOFA, 2020).

2.2.1 History of coffee production in Ghana

The history of Robusta coffee production in Ghana dates back to the mid-eighteenth century. It grows in almost all parts of the country where cocoa grows, as well as in areas that are marginal to cocoa production. However, despite its history and the immense potential that the country has to produce and generate considerable revenues to the nation, coffee has never been given due attention at any time in the past like cocoa (ICO, 2018).

Although coffee cultivation was introduced in the mid-eighteenth century, it represents a small sector with an average production below 1,000 metric tonnes, compared to over 900,000 tonnes for cocoa. Robusta coffee is the type of coffee grown in the country with a growing season that runs from October to September. Coffee production covers 17,000 hectares and the average yield is 300kg per hectare for small-scale farmers and over 1.5 tonnes per hectare for large farms (ICO, 2018). As the sector is the main source of income for over 8,000 households of small-scale farmers from six regions of the country, the Government approved in 2014 a Coffee

Rehabilitation Program (CRP) that includes research, extension services and high yield varieties to increase national production to 100,000 tonnes in the next 10 years. The project provided technical and financial supports to over 4,500 small scale farmers of which 22 % are women. Coffee farming is a profitable activity for small scale farmers and it should be noted that the coffee sector is regulated by the Ghana Cocoa Board (COCOBOD), a public institution in charge of cocoa. The main destinations of exports are Togo (57 % of total exports), Italy (28 %), India (7 %) and Belgium (5 %). With the undergoing revitalization of the sector, based on strong support of the government, it is expected that the share of coffee in GDP, and in total exports will increase in the near future, as well as domestic coffee consumption (MOFA, 2020).

The Annual General Assembly of the Inter African Coffee Organization (IACO) held in Accra, Ghana, in November 2009 was a great impetus to re-emphasize coffee, as a result of which the government, through the Cocoa Board, allocated around US$4.5 million for a four-year period to double the production (ICO, 2018).

Unfortunately, low coffee prices and the withdrawal of state assistance over the past two decades have deprived farmers of all the advantages that made the sector so attractive, bringing about a gradual decline in the activity. This situation has gradually undermined interest in this crop that provided work for the populations of whole regions, causing virtually irreversible loss of dynamism, despite the considerable efforts that have been increasingly made since the structural adjustment point was reached (ICO, 2018).

The current contribution of the coffee sector to Ghana's GDP is very small and almost insignificant. It has always been less than 0.2 % of GDP. The six-year export analysis show that Togo remains Ghana's major export destination of coffee, 57 % of Ghana's coffee is exported to Togo, followed by exports of 28 % to Italy (GSS, 2019).

ICO (2018) coffee is an important global export commodity and is one of the most consumed beverages in the world. Government's efforts to diversify export commodities have brought about the need to revive the coffee industry in Ghana.

Similar to many other West African countries, Ghana solely produces *Coffea canephora*, commonly called Robusta coffee, because of ecological limitations of growing the other most important commercial species, Coffea *arabica*.

2.2.2 Impact of coffee production on the environment

Coffee grows in the forest and transition belt of Ghana. Together with cocoa, rubber and palm oil, these products have been responsible, to a large extent, for deforestation in Ghana. COCOBOD has put in place several programmes and policies such as the Environmental Sustainability Programme, Forest Investment Project (FIP), Climate Smart Production and a few small initiatives with third party organizations to either mitigate or prevent further deforestation (MOFA, 2020).

Use of agrochemicals in the coffee sector in Ghana is very minimal as most coffee farmers naturally cannot afford to purchase the chemicals. Most of the waste from coffee is used as mulch on the farm or gardens in Ghana. There is no government policy at the moment for the use or disposal of coffee waste as the volumes are quite small (ICO, 2018).

2.3 Cashew (*Anacardium occidentale L.*)

Cashew (Anacardium occidentale L.) is a tropical tree native to South America, which is currently grown in most tropical countries around the world. Although this species was introduced in West Africa in the middle of the 16th century (Salam and Peter 2010). The establishment of cashew as a cash crop began in the 1950s and became an intensively grown cash crop since the 1990s (Salam and Peter, 2010).

Cashew production has been steadily increasing over recent years, which is more down to an increase in the cultivated area from 1,963,000 ha in 1992 to greater than 5,300,000 ha in 2011 (FAO, 2013) than an increase in productivity per hectare, which almost doubled from 475 to 805 kg/ha in the same reference period (FAO, 2013). In 2011, about 4.7 million tons of raw nuts was produced worldwide, almost equally distributed between Asia and Africa, whereas almost 1.8 million tons over 2 million tons of cashew apples were produced in South America, namely, Brazil (FAO, 2013). The growing interest in cashew crop is shown by the evidence that cashew kernel, the main product cashew is cropped for, is a high-value luxury commodity with steadily growing production volumes and sales over the last 20 years (FAO, 2013).

What is more, cashew has been mainly produced in emerging countries where it is an agricultural commodity that significantly contributes to gross domestic product, export exchanges at the country level and an essential source for the livelihood of smallholder farmers that make up the majority of the producers and processors worldwide (Fitzpatrick, 2011). Therefore, the cashew industry plays an important role in the economic development of countries like Vietnam, India, Nigeria, Ivory Coast, and Ghana and should thus be considered a key contributor to the achievement of the United Nations Millennium Development Goals. Indeed, the cashew industry could be positively exploited in this sense for empowering smallholder farmers with a particular focus on women, creating revenues and employment opportunities, and promoting small to medium-scale industrialization processes, especially in rural areas. Among the non-traditional export tree crops with the greatest potential, cashew stands out both in terms of volume and value. West Africa is one of the most recent and dynamic in the world cashew production (FAO, 2016), accounting alone for 45 % of the worldwide production of cashew nuts in 2015 (Rabany *et al.,* 2015). In 2018 Ghana produced $378 m worth of cashew, an increase of 43.8 % on the previous year and a 17-fold jump on the $20 m produced in 2009. From a cost perspective, cashew offers attractive returns: its inputs typically cost no more than those required for maize production. As such, it is anticipated that cashew will continue to replace staple crops in the Bono East, Bono and Ahafo regions at a rapid pace. While these headline figures are promising, much of this recent growth was due to higher global cashew prices triggered by 7% annual demand growth. However, the export value for 2019 is expected to drop, as cashew prices fell by as much 75% early in the year (MOFA, 2020).

2.3.1 Influence of cashew production on the environment

Cashew plantations stand apart among other tree species because of their increasing importance in terms of areas and alternative to reforestation. It is among the world's top nut export crops with 7 million hectares of plantation (FAO, 2015).

The cultivation of the cashew tree is therefore an economic activity that preserves and restores the environment. The use of cashew plantations is a sustainable solution for combating human pressure on tree species (Tandjiékpon *et al*., 2003). According to Boillereau and Adam (2007), these plantations contributed to good carbon sequestration.

Tree crops store carbon in tree biomass, in the root and the aerial biomass (Peichl *et al*., 2006). Indeed, the chlorophyll plants take photosynthesis of the CO_2 in the atmosphere that they assimilate for their maintenance, growth and energy needs. These ecosystems lose large quantities of carbon actually re-emitted into the atmosphere in the form of CO_2 through respiration and cashew plantations are not exception to this process (Tandjiékpon, 2010).

2.4 Mango (Mangifera *indica*)

Commercial farming of grafted mango varieties has been increasingly adopted by Ghanaian farmers since the late 1990s, mainly due to programs on food security sponsored by the United States Agency for International Development (USAID) and efforts of the Ministry of Food and Agriculture (MOFA) and other Ghanaian government programs. Over the past ten years, because of increased demand for mango on overseas markets, the mango sector has captured the attention of farmers and traders (MOFA, 2020).

According to TIPCEE (2009), mango production is estimated to be at 40,000 tonnes per annum and spread over 17,000 hectares. Although mango trees can be found all over Ghana, commercial production is mainly found in two distinctive agro-ecological zones: Northern Ghana around Tamale and Southern Ghana (Greater Accra, Eastern and Volta Regions). Half of the production (close to 20,000 tonnes) is located within the Eastern Region on more than 5,200 hectares, while Brong-Ahafo and Greater Accra produce 18 % and 16 % of national mango outputs, respectively. Production conditions in Northern Ghana are similar to those in the major mango production zone of Sikasso in Mali, Korhogo in Cote d’Ivoire and Bobo Dioulasso in Burkina Faso, with a harvest season running from March (for early varieties) to June (late varieties) (Zakari, 2012).

The Ghanaian mango sector has developed a decade later in the context of a food security programme financed by USAID and, in addition, value chain as well as trade and investment projects supported by USAID and GIZ. Since 2012, the Export Development and Agricultural Investment Fund (EDAIF) of the Ghanaian government has been supporting the sector more actively (Grumiller *et al.,* 2018).

Mango production stands at around 110,000 tons and contributes 0.3 % of agricultural GDP. Output is expected to increase significantly in the next years due to a government supported planting program. With post-harvest losses of around 30 % (MOFA, 2016), the volumes available for processing were roughly 30,000 tons, while usually 40,000 tons are consumed locally as fresh products. With 800-1,000 tons of dried mango exports, Ghana was second in West Africa to Burkina Faso, which exports about 2,000 tons per year. Fresh exports moved within the boundaries of only 800 to 2,000 tons per year (FAOSTAT, 2017). According to FAO (2019), Africa mango production grew from 3 958.3 thousand tonnes in 2008 to 8 209.1 in 2018. That's over 100 percent increase.

Ghana's unique climate provides a comparative advantage over neighbouring countries because it has two harvest seasons in the south (peak and minor season, a short one December to February-complement the traditional April to July production period). Ghana grows a number of mango varieties; however, the vast majority is made of Keitt (approx. 80% or 24,000 t.), Kent (10% or about 3,000 t.). The other fourteen varieties (Palmer, Tommy Atkins, Zill, etc.) amount to very low quantities. Region wise, Greater Accra, Volta, Eastern, Brong Ahafo and the Northern regions of Ghana are noted for mango production (Grumiller, *et al.,* 2018).

2.5 Forest

Forest is land spanning more than 0.5 ha with trees higher than 5 metres and canopy cover of more than 10 percent, or trees able to reach these thresholds in situ (FAO, 2010). It does not include land that is predominantly under agricultural or urban land use. Wooded land is land not classified as forest, spanning more than 0.5 ha; with trees higher than 5 metres and canopy cover of 5–10%, or trees able to reach these thresholds in-situ, or with a combined cover of shrubs, bushes and trees above 10 % (FAO, 2010),

Forests cover about 30 % of the Earth's land area. At all spatial scales, from local to global, trees and forests play a critical role in human livelihoods, as well as in ecosystem functioning and health (FAO, 2012). In many local communities worldwide, people have a daily dependence on forests, engaging in fuel wood-gathering, the harvesting of wood and non-wood forest products, and community-based forest management. Forests also provide wood for larger-scale commercial purposes, habitat for more than half the world's terrestrial species, clean water, and other important ecosystem services (FAO, 2012).

In Ghana, an extensive forest estate, consisting of 1.6 million hectares of forest reserves, was gazetted in the High Forest Zone (HFZ) in the 1920s (Oduro *et al*., 2012). As at that time, there were large areas of forests outside these gazetted forest reserves across the country. Over the period, significant portions of these forests have been lost or degraded. The key underlying causes of deforestation and forest degradation include population and economic growth and weak governance structures. Additionally, growing domestic and export demand for agricultural commodities such as cocoa, oil palm, cashew, coffee, mango and food crops has led to large scale conversion of forests to agricultural uses (Oduro *et al*., 2012).

GFPS (2016) reported that the principal drivers of deforestation and forest degradation in Ghana have been identified as agricultural expansion (e.g. permanent cultivation, free range cattle ranching, shifting cultivation/traditional slash and burn), wildfires, logging and fuel wood harvesting, mining, and infrastructural development (roads, settlements and other infrastructural development).

Forest trees are known to bring about changes in edaphic, micro-climatic, flora, fauna and other components of the eco-system through bio-recycling of mineral elements, temperature and moisture regime modifications and changes in flora and fauna composition among others (Oladele and Adeyemo, 2016). Furthermore, they also help to improve the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching and by increasing nutrient inputs through nitrogen fixation and increase biological activities by providing biomass and suitable microclimate (Ogunkunle and Awotoye, 2011).

Forest ecosystems contain terrestrial carbon since they store huge quantities of carbon in different pools such as vegetation, litter, and soil and exchange big amounts of C with the atmosphere through respiration and photosynthesis. Among the organic carbon reservoirs in forests, the soil stores large quantities of organic carbon, accumulating C as soil organic matter (SOM). Indeed, soils have been accepted as the largest terrestrial carbon pool because of the greater C content than terrestrial vegetation and atmospheric C (Daouda *et al.,* 2017). Understanding the condition and changes through time of the globally valuable forest resource is important for human well-being and ecosystem health. For example, land-cover and land-use change can potentially affect regional and global climates by emitting or sequestering carbon (Pan *et al*., 2011).

Olojugba (2018), reported that, forest and closure of tree canopy afford the soil adequate cover, thereby reducing the loss in nutrients that are essential for the growth of plants. Available nutrients estimation in soil has genesis of soil as well as ecological importance which is partially controlled by forest and vegetation. At different level, forest cover also helps in protecting the soil from harsh climate, mostly rainfall and sunlight (Olojugba, 2018).

2.5.1 Impact of forests on soil quality and the environment

The term “soil quality” is used here in the sense as described by Doran and Zeiss (2000), who use it in context or synonymously to soil health, the “quality” of a soil being represented by a “suit of physical, chemical, and biological properties”. Soil health, however, focuses more on the biotic components of a soil, reflecting, i.e., the maintenance of soil organisms and their proper functioning as regulators of nutrient cycling and therewith of soil fertility.

Soil quality cannot be directly measured, and soil quality information is usually deduced from observed or modelled soil physical, chemical, or biological attributes (Kiani *et al.,* 2017). Within the context of agricultural production, Karlen *et al*., (2006) attributed high soil quality to be equivalent to long term high productivity and the system resiliency without significant soil or environmental degradation. Nanganoa (2019), outlined five soil functions that may be used as criteria for judging the soil quality: to hold and release water to plants, streams, and subsoil; to hold and release nutrients and other chemicals; to promote and sustain root growth; to respond to management and resist degradation; and to maintain suitable soil biotic habitats.

The soil condition is a very essential factor in the productivity of forest ecosystems and the hydrologic functioning of watersheds. Tropical rainforests have the ability to ameliorate and perform as a regulator of greenhouse gases (Karam *et al*., 2013). Despite its crucial role as greenhouse regulator, natural forests are faced with immense deforestation, resulting in loss of biodiversity and reduction in soil fertility (Daljit *et al*., 2013). Thus, the conversion of forest reserves to other land use systems in recent times has resulted in many complex changes in the forest ecosystem with significant ecological problems (Mhawish, 2015). According to Ago *et al*. (2016), forest resources and ecosystems are essential to climate resilience as they help to conserve water resources, provide food, reduce the impact of natural disasters and provide the organic matter that improves soil fertility, carbon storage and farmers' livelihood.

When deforested land is abandoned, it regenerates in successional stages, which can be easily observed by varying stages of vegetation reestablishment. During this process the soil, in conjunction, will regenerate, restoring natural physical properties, chemical processes, and the microbial population (Schembre, 2009). Thus, forests filter and regulate the flow of water due to their leafy canopy that intercepts rainfall, slowing its fall to the ground and the forest floor before gradually releasing it to natural channels and recharging ground water (Penn State Extension, 2008).

2.6 Soil

Soil, the unconsolidated cover of the earth, consists of inorganic (mineral) and organic components, water, air, and living organisms. Soil is a biochemically and physically weathered product of rocks and minerals through biological and chemical activity. Soils provide nutrients for plants and are capable of supporting plant growth and a home to a wide range of organisms and a repository for soil C (Buckman and Brady, 1970). It is a key compartment for climate regulation as a source of greenhouse gases (GHGs) emissions and as a sink of carbon (Bispo *et al.,* 2017).

Soils, especially managed agricultural soils, have the potential to store (sequester) carbon (C) and contribute to mitigation of GHGs emissions. Increasing the amount of organic C in soils may not only mitigate GHG emissions, but also benefit agricultural productivity through improvements in soil health and environmental quality by reducing soil erosion (Pacala and Socolow, 2004).

Globally, soils contain about 3 times more C than the atmosphere and 4.5 times more C than all living things. A relatively small increase in C content in soils can make a significant contribution to reducing atmospheric CO_2 levels (Xiao, 2015). It is estimated that increasing SOM content up to a 2-meter depth by 5-15 % could decrease atmospheric CO_2 concentrations by 16-30% (Baldock, 2007; Kell, 2011). The surface soil plays a significant role in ecosystem function both as source and sink of nutrients (Mhawish, 2015).

2.7 Soil Carbon, Soil Carbon Stocks and Soil Carbon Sequestration

Carbon cycle is the process where carbon compounds are interchanged among the biosphere, geosphere, pedosphere, hydrosphere, and atmosphere of the earth, (Figure 2.1).

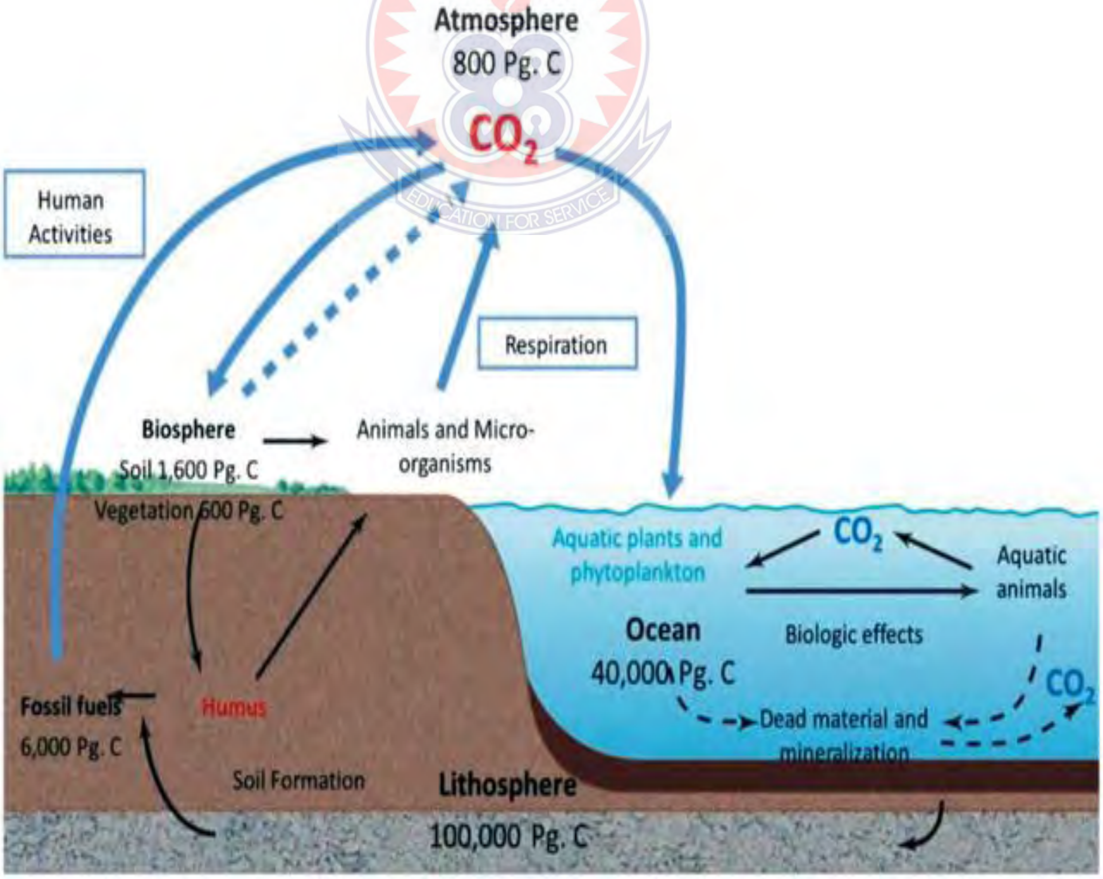

Figure 2. 1 Graphical illustration of carbon cycle

Source: (Babur and Dindaroglu, 2020)

2.7.1 Carbon and Soil organic carbon

Carbon exists as inseparable component of biomass and soil organic matter. Its storage in soil organic matter is important in mitigating global climate change and improving the livelihood of resource-poor farmers. It increases land productivity through improved soil properties such as nutrient supply and moisture retention (Naik, Maurya and Bhatt, 2016).

According to Batjes (2011), $2.2\text{x}10^{12}$ t of carbon are stored in the top 1 m of soils, globally. This amount is thrice the amount of atmospheric carbon. In the last decades, atmospheric C concentration is known to increase with anthropogenic carbon emissions (ACEs) (e.g., fossil fuel combustion and cement manufacturing).

The ACE was 6 Pg year^{-1} in the 1980s (Lal and Follett, 2009); it increased to 10 Pg year^{-1} in 2014 (Zeebe *et al.,* 2016). This caused a significant increase in global warming.

Globally, soil organic carbon (SOC) is one of the largest and active carbon pools. SOC stores approximately1200 to 1600 Pg C in the 100 cm depth, which contains more carbon than in the terrestrial vegetation (approx. 600 Pg C) and in the atmosphere (approx. 800 Pg C) (FAO and ITPS, 2015).

A review of published SOC studies showed, in general, that SOC content, and its fractions, differs significantly among land-use types. For the top soils of the whole of Germany, Düwel *et al.* (2007) stated that the land-use ranking (with increasing SOC content) as being cropland < forest < grassland, by analysing data that were mainly obtained between 1985 and 2005. Further SOC comparisons in the German region were performed by Wiesmeier *et al.* (2012) where the ascending order for the SOC content of Bavarian (southeast Germany) top soils was cropland < grassland < forest. Chen *et al.* (2009) compared SOC content of Baden-Württemberg’s (southwest Germany) cropland and grassland soils, in three depth intervals up to a depth of 20 cm, and reported that grassland soils had higher content of SOC than cropland sites in the uppermost five centimetres.

Bhavya *et al.* (2017) observed that carbon content differed significantly with different cropping system, the mango orchard had higher organic carbon content i.e., 6500.00 and 6316.00, mg kg^{-1} at 0-15 cm and 15-30 cm, depths respectively which was followed by cashew orchard whereas, the medicinal and aromatic block had lowest organic carbon 4300.00 and 3916.00, mg kg^{-1} at 0-15 cm and15-30 cm, depths respectively. This is due to the continuous addition of organic matter by continuous falling of leaves in perennials crops like mango and cashew orchard which leads to accumulation of more organic matter to the soil. Since organic manures are incorporated in to the surface and a major portion of the left-over residues of shallow rooted crops usually accumulate in the top few centimetres of the soil layers, there was possibility for a relatively greater accumulation of organic carbon in 0-15 cm soil as compared to the soils of lower layer. Similarly, Osei *et al.* (2018) observed that when *Mucuna prurience* was incorporated as green manure it significantly increased the soil organic carbon content of the soil.

Poeplau and Don (2013) reported soil organic carbon losses, which were largest in topsoil (0–10 cm) and ranged from 61 % to 77 % as a result of grassland to cropland conversion.

Apart from the effects of different land-uses, soil organic carbon content - and therefore microbial biomass carbon – also depends on abiotic soil properties resulting from the physical and chemical qualities of the parent material. Deng *et al.* (2016) reported that a decrease in SOC and litter input could lead to a decrease of soil microbial biomass, since SOC and litter are the substrates necessary for the living of microorganism. SOC in the soil surface depends on the quantity of above-ground organic matter inputs and its development is influenced by soil type, climate, management and the SOC-storage capacity of the soil (Carter *et al*., 2002). Also, SOC density generally increases with increasing precipitation and there is an increase in SOC density with decreasing temperature for any particular level of precipitation (Bessah, 2014)

2.7. 2 Carbon Sink/Source

Carbon sink is a reservoir that stores carbon and its related compounds for a very long period (Battin *et al.,* 2009). This reservoir can either be natural or artificial. Some of the natural carbon sinks are the oceans, soil, and vegetation. This same sink can be turned into source when they release more carbon into the atmosphere than they absorb. Globally, it has been proven that continuous agriculture makes soils to be a vital source of atmospheric CO_2 and other greenhouse gases contributing substantial percentage to global warming (Powlson *et al.,* 2011a).

Surface soils (0–30 cm depth), which store almost half of soil organic carbon (SOC) and up to three times the C stored aboveground in vegetation, are considered to be the most vulnerable to loss as CO_2 emissions due to climatic and land-management change, highlighting a major threat to climate regulation (Powlson *et al*. 2011a)

In general, tropical ecosystems are considered as sources rather than sinks of CO_2 since the savanna is grown and wood is harvested for energy and coal production (Tinlot, 2010).

2.7.3 Soil carbon Stock

Natural and anthropogenic disturbances influence soil C stocks by affecting rates of organic matter input and decomposition. Natural disturbances such as wildfire, pests, diseases and wind throw can temporarily reduce soil C stocks of forests (Zhang *et al*., 2015). Anthropogenic disturbance, related to both conversion of forests to other land uses, and modifications of forests involved in the provision of forest products and services also influence forest soil C stocks (James and Harrison, 2016).

Gebeyehu *et al.* (2019), studied the effect of disturbance severity on C stocks by assessing the harvesting and canopy openness due to removal of trees with stem diameter ≥ 5 cm. The disturbance level (number of stems removed from the forest) resulted in a decrease in aboveground C stocks of 36 % in the highly disturbed compared with least-disturbed forest. A negative correlation between the canopy openness and soil C stocks indicated that increasing canopy openness was associated with decreasing soil C stocks**.**

Daouda *et al.* (2017) reported that high carbon stock was recorded in the transitional zone (84.84 ± 4.06 t C /ha) against 63.14 ± 3.78 t C /ha in the Sudanian zone. In general, 78.9% of the carbon stock was found in the trunk of the trees against 19% and 2.1% respectively in the branches and in the leaves.

Carbon stocks are higher under the perennial horticulture crops as compared to annual crops. This is due to the continuous addition of organic matter under perennial crops which leads to continuous decomposition of the accumulated organic matter under the system. The thick litter also reduced the amount of CO_2 gas emitted into the atmosphere. The implication is that, crop residue application as surface mulch could play an important role in the maintenance of soil organic carbon levels and productivity (Kyere *et al.*, 2018).

Daouda *et al.* (2017) in their work on assessment of organic carbon stock in cashew plantations found out that, low carbon content of the soil in cashew plantations could be explained by the higher decomposition of the organic matter linked to the higher temperatures observed in the study area. The carbon stock in the organic matter in their study varied between 2.58 ± 0.34 t C/ha and 4.26 ± 0.35 t C/ha. This result is similar to 2.8 t C/ha determined by the IPCC (2003). The high rate of carbon could be explained by the quality of the litter. The total carbon stock in the cashew plantations ranges from 63.14 ± 3.78 t C/ha to 84.84 ± 4.06 t C/ha. Similar research conducted by Rupa *et al*. (2013) in India showed that, 7-year-old cashew plantations of between 156 and 600 trees per hectare stored between 32.25 and 59.22 t C / ha.

2.7.4 Carbon sequestration

Carbon sequestration by terrestrial ecosystem is the net removal of carbon dioxide (CO_2) gas from the atmosphere or the avoidance of its emissions from terrestrial ecosystems into the atmosphere. The removal process includes CO_2 uptake from the atmosphere by green plants through photosynthesis and the carbon stored as plant biomass (in the trunks, branches, leaves).

Again, West and Marland (2002), defined carbon sequestration as an increase in the stocks of carbon in any reservoir other than the atmosphere is known as carbon sequestration. In this regard, soils are considered as the largest carbon reservoir of the carbon cycle. The ability to capture and secure storage of carbon in soils is a function of depth, texture, structure, rainfall/irrigation, temperature, farming system, soil management and tillage, cropping intensity and nitrogen inputs to soil (Del-Grosso *et al*., 2008).

Carbon additions to surface soil through litter fall and external additions are subject to rapid decomposition and release of CO_2, with only a small percentage of C becoming stable C in ‘long-lived’ pools. If C stocks increase through time, that is a form of sequestration (Nair and Nair, 2014).

Most of the factors affecting carbon sequestration are affected by land management practices. The distortion in the global carbon balance through human activities is due to the burning of fossil fuel and cement production (67%) and agriculture and land use change (33%) (FAO, 2004). Some limiting factors constraining carbon sequestration include: Physical degradation due to erosion, Chemical degradation due to nutrient mining and acidification, biological degradation due to loss of organic matter through removal of vegetation in the farm of forest clearing and rampant burning of vegetation (Naaganoa *et al.,* 2019).

Carbon sequestration potential of agroforestry systems vary for different species and locations. Cocoa agroforests contained significant levels of tree diversity and C stocks, and have the potential to sequester significant amounts of C. They are however a poor substitute for the natural forest except in instances where farmers are converting their agroforestry systems to cocoa monocultures (Mutuo *et al*., 2005).

According to Bhavya *et al.* (2017), carbon sequestration is less under the annual cropping systems as compared to the perennial crops. This is due to the land use changes and soil degradation processes as well as the rapid decomposition of organic matter in cultivated soils were the major causes for the release of CO_2 from the systems, as the land use systems that added more residues recorded less emissions of CO_2. They also asserted, cultivation of annual crops reduces the carbon pools and increase CO_2 emission.

Carbon sequestrated in the soil varied between 80.99 and 45.88% according to the zones. As observed by Daouda *et al.* (2017) where transitional zone and Sudanian Zone significantly sequestered carbon different.

2.7.5 Litter fall and organic matter

According to Tian *et al.* (2015), litter-fall contributes significantly to soil organic matter in forest biomes, and together with soil microorganisms makes forest soils productive for agriculture in the tropics. Beneficial effects of litter fall have been reported in temperate and tropical agricultural management systems, including increased soil organic matter content, higher levels of available nutrients, increased concentration of nutrients at surface layers, reduced leaching losses of nutrients, better erosion control, improved soil structure and texture, decreased soil acidity and compaction, reduced fertilizer input costs, improved water holding capacity, increased biological activities, weed suppression, decreased disease, and reduced pest problems (Kahimba *et al.,* 2008; Fageria *et al*., 2010; Buyer *et al.,* 2017).

In West Africa, plantation crops are crops of economic importance and they consist of oil palm, rubber, cashew, oranges, mango, cocoa, coffee etc. Every year these crops take nutrients from the soil and some are returned through litter fall and decomposition of these litter. The litter fall from these plantations have ability to increase soil organic carbon (Njar *et al.,* 2011; Lu *et. al.,* 2013). Due to the large-scale planting of plantation crops (MOFA, 2020), they have the capacity to sequester C. Thus, large scale planting of these crops and biomass production could contribute to soil C sequestration.

SOM is a complex mixture of carbon compounds made up of decomposing plant and animal tissue, microbes, and carbon in soil minerals (ESA, 2000). Soil organic matter (SOM) is one of the most essential soil components that contributes to ecosystem productivity through its positive effects on soil structure, aeration and porosity, maintaining soil water and temperature (Prescott *et al.,* 2000). Moreover, SOM has a strong relation with nutrients availability, because it is an important nutrient source that can be used by plants in long periods. Besides, SOM contributes to forming soil structure and increases water holding capacity in soils (Babur and Dindaroglu, 2020).

SOM is higher in forests than other land use types. Also, the productivity of forest ecosystems depends on soil physical, chemical, and biological characteristics and processes (Blanco *et al.,* 2017).

Labile fractions of soil organic matter (SOM), such as particulate organic matter (POM), particulate organic carbon (POC) and particulate organic nitrogen (PON) and dissolved organic matter (DOM): dissolved organic Carbon (DOC): Complex carbon compounds that are sometimes considered part of soil organic matter, but are easily transferred by water from surface to subsurface horizons, primarily responsible for transfer of organic compounds to the B horizon and dissolved organic nitrogen (DON), are known as energy sources for soil organisms. SOM fractions are suitable indicators for the evaluation of the effects of land use changes on biogeochemical cycling and topsoil quality (Kooch and Noghre, 2020). High OM in forestlands is as a result of tree leaves, stems, barks, flowers, logs, and fruits. In addition, microorganisms, animals, and roots contribute to the increase of OM (Bizuhoraho *et al.,* 2018).

2.7.6 Decomposition

Decomposition is the breakdown of organic compounds by soil microbes. Primarily, dependent on temperature and moisture availability, as well as nitrogen availability. This is the primary mechanism of carbon loss from soils. In particular, litter decomposition plays an important role in nutrient cycling and organic matter turnover within ecosystems (Smith and Bradford, 2003) and is important determinant for maintaining the biosphere; it also performs unique and indispensable activities on which larger organisms including humans depend (Panda *et al.,* 2010).

Soil organic matter (SOM) decomposition process is dependent on substrate type and quality (fragment type and size, decay stage, nutrient availability, and tree species) and amount and activity of the soil microorganisms and environmental factors (climate, soil texture, structure, soil chemical compounds, soil moisture and temperature, aggregation soil nutrient availability and temperature) (Babur, 2019).

2.7.7.1 Factors affecting decomposition

Decomposition turns to be affected by rainfall as confirmed by Manlay *et al.,* (2004). Maximum decomposition was recorded during the rainy season followed by winter and summer months both in plantations as observed by Panda *et al.,* (2010). The high rate of decomposition in rainy season was attributed to the suitable moisture (rainfall) and micro-fungal population. Similar observation has also been made earlier (Sarjubala and Yadav, 2007). Much lower rate of decomposition during summer may be due to paucity of soil water and low microbial load resulting from low rainfall (Sarjubala and Yadav, 2007).

Very high rainfall observed at the peak of rains (June-July to September), enhanced better decomposition and accumulation of soil organic carbon, which might be a reason for the distribution of organic carbon across the seasons (Fatubarin and Olojugba, 2014).

Soil microbial population also affects decomposition. This is confirmed in Sparling (1997), who reported that, soil microbial respiration is one of the most important microbial indices first calculated in the majority of models. Microbial soil respiration explains all activity or energy consumption of the microbial communities; therefore, it is the main parameter to observe decomposition rate.

Bonus (2007), reported high temperatures in the tropics, for example in Ghana (29.8 – 37.9 °C) promote rapid decomposition of soil organic carbon and the release of carbon dioxide into the atmosphere to compound the problem of global warning.

2.8 Soil Hydrology

The hydrologic cycle refers to the fate of water in and on planet Earth, from the time precipitation falls on the Earth's surface until the water is returned to Earth's atmosphere (Figure 2.2). The general principle is simple, and the driving force behind it comes primarily from the Sun's solar energy (Jirka *et al*., 2007).

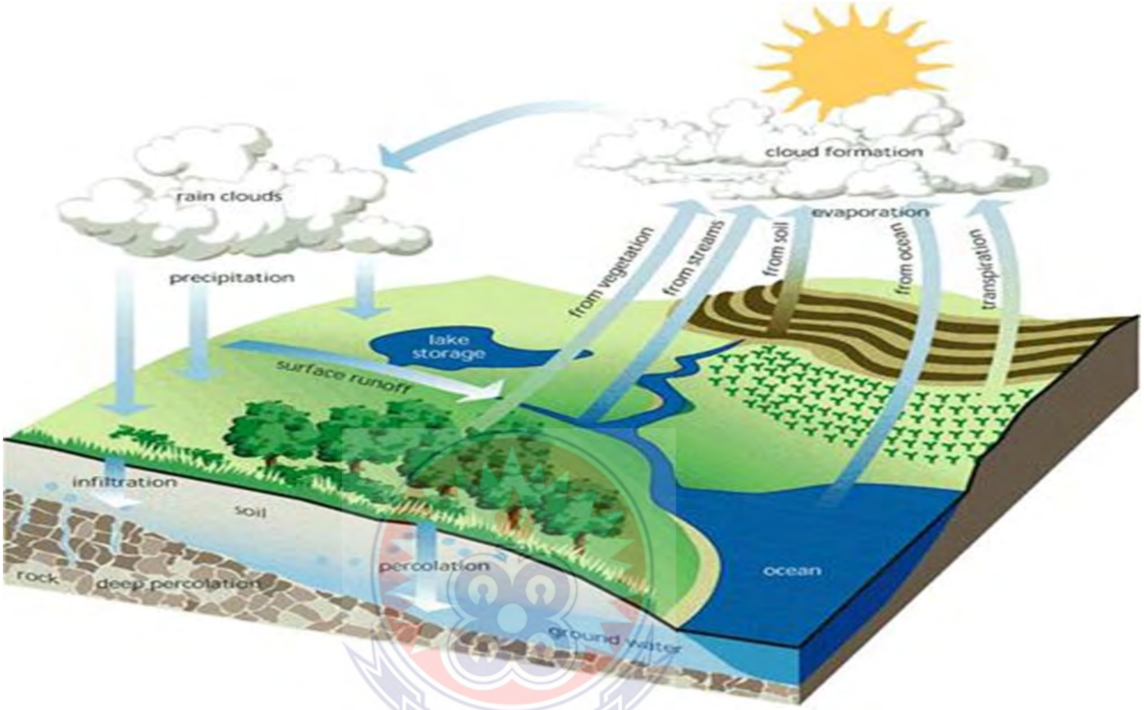

Figure 2. 2 Graphical representation of soil hydrology

Source: Tom Schultz (Courtesy of Iowa State University Department of Natural Resource Ecology and Management)
http://www.h2owell.com/hydro_cycle_pic.htm

Soil hydrology is a component of the environment that could play a strong role in shaping tropical forest structure and composition (Jirka *et al*., 2007). Water movement through terrestrial subsurface mainly occurs by infiltration, evapotranspiration, percolation to groundwater, and capillary rise from the groundwater table. The physical and biochemical properties of soil and its vegetation cover greatly influence these processes. In general, the dynamics of the soil water budget comprise the main components of precipitation, infiltration, capillary rise, evapotranspiration, surface runoff, inter (or soil) flow and groundwater (Rose *et al.,* 2005).

The inter connection between the water balance elements can have a strong impact on the plant available soil water content, consequently influencing the choice of crop farming and cultivation techniques (Horel, 2015).

Assefa *et al.* (2020) reported that knowledge of the soil water content variations in different environments and in different seasons of the year is important to several fields of study. Also, according to Feltrin *et al.* (2013), knowledge of how this variation in soil water content behaves is important for the adoption of adequate techniques for soil management and conservation.

Soil moisture occurs as a balance between the competing demands of the atmosphere, vegetation, and gravitational drainage (Williams *et al*., 2009). The soil water content is a variable of great importance in various hydrological processes including land-atmosphere interactions (evaporation and precipitation), flooding, erosion, solute transport and its form of availability are crucial for the growth and development of plants. It influences the dissolution, soil biological activity, soil temperature variation and oxidation and reduction state of soil matrix (Adhikari *et al*., 2009).

According to Salvador *et al.* (2012), the heterogeneity of soils and their properties make soil water storage vary considerably in space and the depth chosen for the study undoubtedly interferes with the magnitude of variability. Soil moisture is often neglected, but improved soil moisture management is crucial for sustainable improvement of food production and water supply (Osei *et al.,* 2017).

2.8.1 Importance of soil moisture

According to Babur and Dindaroglu (2020), plants contain a certain amount of water within them, which acts as a buffer against times of water shortage, but the amount is too small to last long. In contrast, plants store sufficient quantities of nutrients within their tissues to provide a buffer for longer periods when nutrients are not being absorbed. Consequently, water deficiencies become more quickly apparent and damaging than nutrient shortages. This suggests that conserving water may often be of prior and quicker benefit than attempting to conserve soil particles per se.

Studies have showed that changes in soil moisture could affect soil respiration by influencing the aboveground biomass and diversity of vegetation. It was also reported that changes in soil moisture could affect (qCO_2) directly or indirectly by influencing substrate C: N and C: P ratios and soil physical properties (Deng *et al.,* 2016).

Inadequate soil moisture also reduces the uptake of nutrients by a crop. This is largely because nutrients can only move to roots through water films within the soil, and so there must be continuous water films connecting the nutrients with the roots. A lack of soil water continuity, due to drought for example, will severely reduce the rate of nutrient uptake by crops (Babur and Dindaroglu, 2020).

A lack of soil water will also diminish nutrient availability by reducing microbial activity, which is responsible for the liberation of nitrogen, phosphorus and sulphur from soil organic matter (Babur and Dindaroglu, 2020). This variation might be due to fluctuations in soil water leading to differential in litter decomposition and subsequently nutrient mineralization.

He *et al.* (2020) showed that soil microbial biomass carbon (MBC) content had a significant positive correlation with soil moisture content, SOC and litter TOC contents ($p < 0.05$) and soil microbial biomass nitrogen (MBN) content had a significant positive correlation with soil moisture content and SOC ($p < 0.01$). The decrease of soil MBC and MBN contents was attributed to the decrease of soil moisture content, SOC content and litter input. Water is critical for the living of microbes and soil water content had significant effects on microbes in both dry and wet environment (Bachar, 2010). On the one hand, although soil aeration conditions were ameliorated under lower soil moisture content, reduced water availability could limit substrate diffusivity and accessibility for soil microbes, and thus inhibited microbial growth (Manzoni *et al.,* 2012).

2.9 Infiltration, Steady State infiltrability, hydraulic conductivity

Infiltration, the term applied to the process of water entry into the soil, generally by downward flow through all or part of the soil surface is known to represent the main hydrological process. The rate of this process, relative to the rate of water supply, determines how much water will enter the root zone, and how much, if any, will run off (Hillel, 1998). Infiltration is a very complex physical phenomenon, since soil is a very heterogeneous and anisotropic layered porous medium (Tuffour et al., 2014). Redistribution, on the other hand, is the movement of water from point-to-point within the soil profile after the infiltration process. After each infiltration event, water movement in the soil continues to redistribute the water below the surface (Rawls et al., 1993).

Infiltration rate is affected by the inherent properties of the soil profile, especially those that strongly affect hydraulic conductivity, diffusivity and water holding capacity (Turner, 2006). These factors include those that influence soil matric forces and pore-space (such as texture, structure, composition and degree of compaction) and surface sealing which is probably the most significant single factor that affects the process (Moore *et al*., 1981). The infiltration rate actually experienced in a given soil depends on the characteristics of the soil layer (especially, its depth, sorptivity and hydraulic conductivity), rainfall intensity, temperature, vegetation cover, amount and distribution of soil moisture, and availability of water at the surface, and land use (Dunne and Leopold, 1978).

Antecedent water content affects in the moisture gradient of the soil at the wetting front, the available pore space to store water and the hydraulic conductivity of the soil. In this regard, initial water content is seen as a critical factor in determining the rate of infiltration and the rate at which the wetting front proceeds through the soil profile. The drier the soil is initially, the steeper the hydraulic gradient and the greater the available storage capacity; both factors increase infiltration rate (Skaggs and Khaleel, 1982).

The hydraulic conductivity (K) of a soil is a measurement of its ability to transmit water; moisture contents related to the water retention curve show the ability of the soil to store water (Klute and Dirksen, 1986) and it is one of the most important soil physical properties for determining infiltration rate, irrigation frequency, drainage practices and other hydrological processes. Hydraulic conductivity is of greatest importance to infiltration rate since it expresses how easily water flows through soil; it is also a measure of the soil's resistance to flow. By definition, diffusivity is directly proportional to hydraulic conductivity, but, usually only the saturated hydraulic conductivity is used in many of the infiltration equations, since it is easier to determine than either the unsaturated hydraulic conductivity or the diffusivity (SSSA, 1975).

According to Horel *et al.* (2015), soil hydraulic properties, such as soil water retention curve (SWRC), soil water diffusivity (D), and soil hydraulic conductivity function (K), are key elements for determining water retention and water movement in soils and, consequently, its accessibility for plant uptake and growth.

Some soil physical characteristics, which affect hydraulic conductivity, are the total porosity, the distribution of pore sizes, and the pore geometry of the soil (Hillel, 1982). Many extrinsic factors (such as traffic, vegetation, or land use) and intrinsic factors (such as soil types, pore size distribution) are responsible for the variation of soil physical and hydraulic properties from field to field in a watershed (Gupta *et al*., 2006).

Soil and crop properties such as soil texture, porosity, bulk density, vegetation types, and root structures can strongly influence the soils' hydraulic properties (Reubens *et al.,* 2007).

Pinto *et al.* (2019) found significant correspondence between the hydrological indicator base flow/runoff and land-uses showing that this hydrological indicator was sensitive to land-use changes in the watersheds. They also suggested that deforestation of the native forest can reduce the Ko, thus decreasing soil water infiltration, groundwater recharge, and water storage capacity. This behavior can increase the surface runoff, the impacts from soil erosion on water yield, and its quality. On small scale catchment, Pinto *et al.* (2017) observed an intrinsic relationship between soil drainable porosity and land-use.

Steady state infiltrability (Ko) affects water flows and other hydrological and biogeochemical processes, including questions about how human-induced changes may affect the ecological balance. However, characterization of Ko covering extensive areas is expensive, long time consuming and complex, especially due to its high spatial variability, as reported in several studies (Kurnianto *et al*., 2019; Wang *et al*., 2018). This high spatial variability of Ko occurs due to different extrinsic and intrinsic factors, including geomorphic surface, weather, land-use and management, soil structure, soil granulometric distribution and bulk density (Zimmermann *et al*., 2013). Such variability may negatively affect the Ko prediction models (Marín-Castro *et al*., 2016).

2.10 Season

A season is a period of the year that is distinguished by special climate conditions, ecology and the number of daylight hours in a given region. Each has its own light, temperature, humidity and weather patterns that repeat yearly. Rainfall, temperature and wind are the most important climatic parameters of agricultural production (Yabi *et al*., 2013).

2.10.1 Effect of seasonal changes on soil organic carbon (SOC) and soil microbial properties

Distribution of SOC on the world map also reflects rainfall distribution with humid areas accumulating more carbon (Victoria *et al*., 2012). Soil moisture which is influenced by soil texture and topography determines the SOC in a climatic zone with temperature as a secondary factor. Biological processes such as decomposition is spade up by increasing temperatures in soils with sufficient amount of moisture, oxygen and nutrient (Batjes, 2011).

Olojugba *et al.* (2018) found that low rains as well as frequent fire in the forest has caused the low percentage of soil organic carbon in the dry season of the year (November-February). The decrease in soil organic carbon in the dry season might be due to little or absence of soil microorganisms that are responsible for the decomposition.

Bolat *et al.* (2015) found that seasonal fluctuations in temperature, moisture and humidity showed significant effects on microbial indexes such as microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), and microbial biomass phosphorus (MBP) in the forest floor and soil because of seasonal fluctuations that alter the climate and biogeochemical process of the soil. In the same study, they stated that, microbial biomass reached the highest populations in the summer season.

Again, seasonal changes in environmental conditions such as humidity and temperature facilitate the microbial biomass cycle, and therefore microbial biomass plays a crucial role in regulating nutrient uptake (Babur and Dindaroglu, 2020). Changes in soil temperature and humidity affect the C mineralization rate, the species structure of the microbial community, and the availability of nutrients from the soil solution (Bargalia *et al.,* 2018).

Climatic factors which do change as per the season in an area do affect soil carbon and other soil properties. It is noted that the temperature has a negative and significant correlation with the carbon stock in the cashew plantations (Reichstein, 2007). As a result, a large amount of sequestered carbon in the study areas induced a reduction in atmospheric CO_2 emission thus attenuating the temperature. This result is consistent with the work of Jayathilaka *et al*. (2012) who explained that high temperature induced a high CO_2 content, contributing to low carbon sequestration.

According to Jayathilaka *et al*. (2012), the increase in temperature leads to a release of carbon from the soil. Contrarily, Daouda *et al.* (2017) reported that temperature and the total carbon stock were significantly and negatively correlated (Pearson correlation coefficient $r = -0.903$ and $P < 0.05$). A rise of the temperature causes the decrease of the stock of carbon in the cashew plantations (Daouda *et al.,* 2017).

2.10.2 Seasonal effect on some soil chemical properties

Seasonal changes affect soil chemical properties. For example, Olujugba *et al.* (2018) reported a decrease in soil nitrogen in March (beginning of rains), While at the onset of rains (June-July to September) and at the waning of rains in November nitrogen contents were increased, which could be as a result of increased activity of nitrogen fixing microbes. Low rainfall which reduced mineralization as well as the distribution of soil organic matter in the area might have accounted for low total nitrogen distribution during the dry season and at the beginning of rains. However, the moderate total nitrogen recorded during the peak of rainfall (June/July and September) might be interlinked with the high rate of mineralization due to high rainfall within the period (Ahmed *et al.,* 2000).

Also, seasonal fires that often happen in the dry season leads to volatilization of nitrogen which is easily lost from system as low as 2000 C. This often accounts for the low nitrogen content in January (dry season) (NurQursyna *et al.,* 2013,).

In Olujugba *et al.* (2018) they reported that the concentration of Ca, Mg, K, Na and TEB decreased in the rainy season, indicating that the exchange site was dominated by H^+ and Al^{3+}. There is the possibility that these basic cations were being eroded and leached since high rainfall occurred during these periods. These findings were in agreement with NurQursyna *et al.* (2013) who were of the opinion that, high precipitation might lead to decrease in exchangeable bases. The decrease in the total exchangeable bases (TEB) during the peak of rainy season at the depths of 10-20 cm could be attributed to the use of these elements for tissue synthesis during this period. There were decline in the soil nutrients (exception: soil nitrogen) at the peak of rainy season, which coincided with the active growth and usage of mineral elements of forest trees (Litton, 2002).

Available phosphorus level was fairly constant in dry seasons (January) and at the beginning of raining season (March) and decreased sharply during the peak of rainfall (September) as a result of growth of plants and accumulation of biomass during growing season (Styles and Coxon, 2007).

For cation exchange capacity (CEC), Olojugba (2018), observed that, excessive amount rainfall between June and September (rain season) was the cause of low CEC observed.

2.11 Land use

Land use is defined by the purposes for which humans exploit the land cover (Lambin, Geist and Lepers, 2003). Land cover is defined by the attributes of the earth's land surface and immediate subsurface, including biota, soil, topography, surface and groundwater, and human structures (Ball, 2001).

Land use change is a complex process shaped by human activities affected by ecological, economic, and social drivers, and capable of influencing a wide range of environmental and economic conditions (McDonald *et al.,* 2000).

One of the main challenges related to the selection of applied land use is implementing sustainable and efficient use of natural resources such as soils and surface and subsurface waters. Due to intensified agricultural production, natural resources encounter increasing anthropogenic pressure. Consequently, the effects of land use and land cover change on soil properties have drawn much attention over the past several decades (Zhou *et al.,* 2008).

The issue of land use change and its impact on terrestrial ecosystems is of great concern, and the importance of protecting natural forests in the context of global climate change and global warming is of great interest (Sloan and Sayer, 2015). The benefit of land use change depends upon what the forest is being converted to; detrimental effects of conversion to managed forest or even monoculture plantations are less than from conversion to row crop agriculture. The impact of converting primary forests to secondary forests may be greater if primary forests are first converted to an agricultural land use (Nave *et al*. 2019).

Land use patterns and vegetation types play important role in soil nutrient mineralization, transformation and fertility potential. Changes in vegetation can occur due to anthropogenic activities, such as changes in agricultural cultivation practices or deforestation, or due to natural sources like wildfire. Changes as a result human influence alter several processes in soil; physical properties such as porosity, soil structure, aggregate stability, soil depth, consistency and water percolation, soil chemical properties such as soil organic matter, nutrient content, total exchangeable bases, availability and cycling, pH and C: N) and biological soil properties such as soil microbial population, soil faunal, biomass productivity and carbon mitigation (Olojugba, 2018).

Muñoz-Rojas *et al,* (2015) land-use changes from forest cover to cultivated land may reduce input or organic residues that lead to a decline in soil fertility, Guimarães *et al.* (2013) increased rates of soil erosion, (Biro *et al.,* 2013) loss of soil organic matter, and nutrients. Wang *et al.* (2012) changes in land cover density and intensification of agriculture aggravate the leaching rate of soil organic matter and nutrients, (Alam *et al.,* 2017) and an accelerated rate of land degradation.

2.11.1 Influence of land use on carbon dynamics

McCarthy *et al*. (2010) reported that conversion of uncultivated land to biofuel agriculture resulted in significant SOC loss, an effect that was most pronounced when native land was converted to sugar cane agriculture. Corn residue harvest (at 25 – 100 % removal) consistently resulted in SOC losses averaging 3 – 8 Mgh^{-1}in the top 30 cm of the soil which is the cropped part of the soil (McCarthy *et al*., 2010).

Land-use change has a much greater impact on soil C than does harvesting. For example, conversion of forest to agriculture caused a large decrease in soil C stocks within the topsoil (0–30 cm) (52 % decrease in temperate regions, 41 % decrease in tropical regions and 31% in boreal regions) (Wei *et al*., 2014).

Bonsu *et al*. (2011) in estimates of CO_2 emissions from soil organic carbon for different land uses indicated that when tropical forest is converted to agricultural land use, the loss of carbon ranges from 7.3 to 49.6%, depending on the type of agricultural land use. When the vegetation is slashed and burnt and planted to maize, carbon loss can be as high as 40.7% compared to the virgin forest.

2.11.2 Impact of land use on soil physical properties

Changes in soil physical properties are highly related to tillage and land clearing methods (Mhawish, 2015). In view of this, conversion of forestland to cultivated land appears to cause large reductions in clay content and increase in sand content. Soils under croplands and grasslands have been reported to possess similar physical properties, while those under forestlands are extensively diverse (Gol and Dengiz, 2008).

Soil physical properties mostly degraded by the effects of mechanical land clearing are bulk density, total porosity, soil moisture content and aggregate stability (Pinto *et al.,* 2019). This is due to soil compaction during forest harvesting, which reduces the volume of macropores and increases the volume of medium-sized pores (mesopores), and increases the potential for surface ponding, and runoff and/or erosion (Tuffour and Bonsu, 2014).

Soil physical properties are considerably influenced by changes in land use and the implementation of conservation practices (Terefe *et al*., 2020). Again, the intensification of soil disturbance through land use change, in general, leads to an increase in soil bulk density, and a decrease in soil water retention as well as plant available (Horel *et al*., 2015). Increase in bulk density as a result of conversion of forest to cultivated land is a reaction of the extent of soil degradation and has been demonstrated by many researchers (Guilser, 2006). High bulk density is an indicator of low soil porosity and high soil compaction. It may cause restrictions to root growth and poor movement of air and water through the soil (Osakwe and Igwe, 2013).

Although change in land use does not change soil texture, texture has an enormous influence on the hydraulic conductivity, diffusivity and water holding capacity of soil with respect to pore size distribution. Thus, soils with higher sand percentages have larger pores, higher hydraulic conductivity, diffusivity and infiltration rates, but lower water holding capacity than clay soils, which have smaller pores, because water molecules tend to bind more tightly to their 10 walls. In this way, it does not participate in normal flow process in the soil (Hillel, 1998). Textural variability may contribute to the variation in nutrient storage and availability, water retention, availability, transport, binding and stability of soil aggregates and the like, hence, may influence yield potential of any site (Adhikari *et al.*, 2009). Also, Crave and Gascuel-Odoux (1997) found that variation in soil moisture content was directly related to the soil textural variability.

Change in land use can lead into compacted soils which in turn degrade soil structure. Soil structure governs the biological activity, physical penetration, growth and anchorage of roots, air and water movement, porosity and so on (Adhikari *et al.*, 2009). Likewise, pore structure of soil aggregates affects the storage of water and its availability for plants. These characteristics are largely influenced by management systems and soil compaction (Lipiec *et al.*, 2006).

2.11.3 Impact of land use on soil chemical properties

It is evident that forest clearing and burning results in severe alterations in soil chemical properties, such as increases in soil pH and cation exchange capacity and volatilization and leaching of nitrogen and loss of organic matter (McGrath *et al*., 2001). Mhawish (2015) observed significant reductions in NO_3 in soil solutions and soil N following forest clearing.

Conventional slash-and-burn practices result in changes that favour the supply of large amounts of available phosphorus in the soil than clearing due to higher composition of ash (Awotoye *et al*., 2013). Thus, slash-and-burn results in conversions of large amounts of unavailable P in soil into readily plant available forms. Calcium and magnesium concentrations in forest soils prior to clearing increase with site quality (Mhawish, 2015). Several studies (Marafa and Chau, 1999) have reported higher concentrations of Ca, Mg and K in the topsoil as a result of burning dried vegetation as compared to mechanical treatment. Rates of exchangeable K, and Ca sorption are considerably higher on clear-cut areas than forest areas (Mhawish, 2015).

2.11.4 Impact of land use on CO_2 emission and C sequestration

Any land use practice that reduces soil quality could lead to a reduction in the SOC pool and an increase of CO_2 emission into the atmosphere. This concords with the findings of Magdoff and Weil (2004) who reported that reduction in soil quality could reduce the productivity of plants.

Melenya *et al.* (2015) reported that soil under the arable land recorded higher emissions of CO_2 than the oil palm plantation and the cocoa plantation under deep litter. Land use change and soil degradation processes as well as rapid decomposition of organic matter in cultivated soils were the major cause for the release of CO_2 from the system as the land use systems that added more residues recorded less emission of CO_2. The conversion of natural vegetation to other uses therefore reduces the carbon pools and increase CO_2 emissions (Melenya *et al.,* 2015).

Bhavya *et al.* (2017) showed that the magnitude of carbon sequestration is more under mango orchard followed by cashew orchard than annual crops like rose, medicinal and aromatic and vegetable block. The carbon dioxide sequestration was significantly greater under the perennial crops as compared to annual crops. It was observed that perennial horticulture crops increase the soil organic carbon (SOC) and carbon dioxide storage than annual crops and reduce the carbon emissions to the atmosphere which helps to mitigate the global warming.

2.11.5 Impact of land use on soil hydraulic properties

According to Horel *et al.* (2015), soil hydraulic properties can influence subsurface water and solute movement. Hydraulic properties can substantially be altered with land use or cover change and by the impact of environmental conditions such as precipitation or temperature changes (Sing and Shi, 2014). Soil hydraulic properties are influenced by the type of the cultivated plants, the seasonal impact, and land use types such as altered agricultural systems (Zhou, 2008).

2.12 Soil microbial properties

Soil microbes play an important role in forest ecosystems through decomposition of organic matter, carbon and nutrient cycling, humic compound incorporation into mineral soils, and linking plant and ecosystem functions (Koranda *et al.,* 2013).

The microbial biomass consists mostly of bacteria and fungi, which decompose crop residues and organic matter in soils. This process releases nutrients, such as nitrogen (N), into the soil that are available for plant uptake. About half the microbial biomass is located in the surface 10 cm of soil and most of the nutrient release also occurs here. Generally, up to 5% of the total organic C and organic N in soils exists in the microbial biomass component of soil organic matter. When microorganisms die, these nutrients are released in forms that can be taken up by plants. The microbial biomass can be a significant source of N, in some cases holding more than 60 kg N/ha (Carson, 2012). Although soil microorganisms are a small part of soil organic material (containing about 2–3% of SOC), it is an important factor that significantly and positively affects carbon storage in soil through the regulation of carbon sequestering, soil respiration, plant productivity and also related to the nutrient mineralization, which plays a crucial role in the biogeochemical cycling of carbon (C), nitrogen (N), and phosphorus (P) in continental ecosystems (Bargalia *et al.,* 2018).

Soil microbial biomass is the dynamic fraction of soil organic matter, which includes fungi, bacteria, actinomycetes, algae, protozoa, and other microfauna and demonstrates an important nutrient pool in the soil. In general, microbial characteristics and the activity of microorganisms and enzymatic processes in soil are biological indicators of soil function useful in evaluating the level of forest degradation or restoration (Liu *et al*., 2019). In different forest sites, C and N cycles are affected by soil microbial activity. The size of microbial populations in soil, especially the microbial biomass C, N, and P, has been introduced as a sensitive indicator of soil function, which plays a very important role in C, N, and P dynamics of forest ecosystems (Kooch, Moghimian and Kolb, 2019).

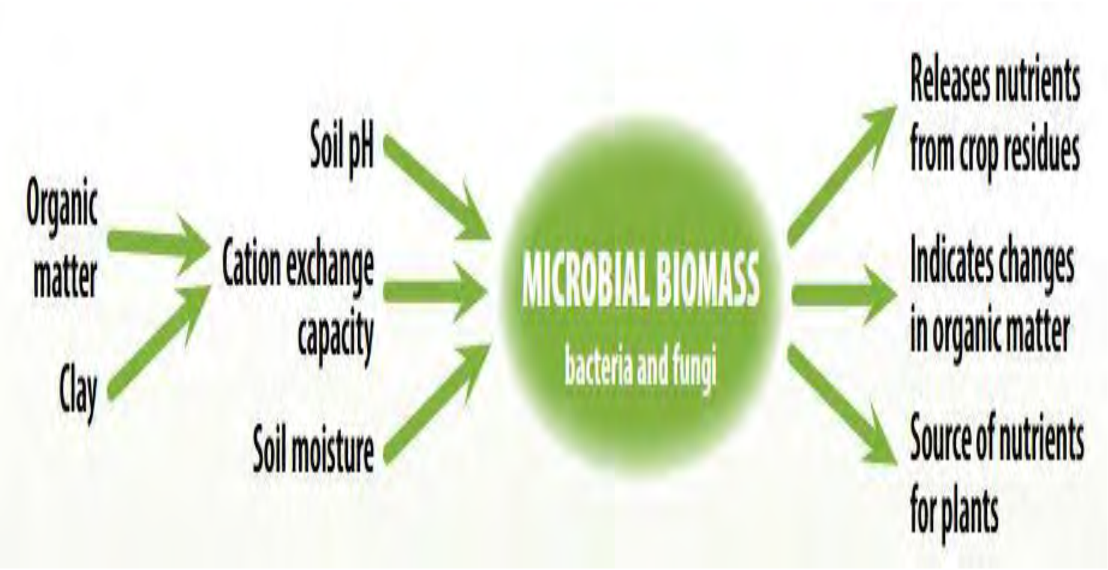

Figure 2. 3 Graphical illustration of soil microbial biomass and its basic functions

Source: (Kooch, Moghimian and Kolb, 2019)

The Microbial quotient (qMIC) serves as a more sensitive indicator of changes in the carbon dynamics than do the content of SOC and MBC separately (Sparling, 1992). The Cmic and the Cmic/SOC, ratio are useful measures to monitor soil organic matter and both provide a more sensitive index than SOC measured alone. (Sparling, 1992). Any changes in the microbial biomass may affect the cycling of soil organic matter (Figure 2.3). Thus, the soil microbial activity has a direct influence on ecosystem stability and fertility (Smith *et al*., 2008). Generally, microbial biomass can offer a means in assessing the soil quality in different vegetation types (Groffman *et al*., 2001).

Small changes in the microbial biomass or community structure could affect organic matter turnover and nutrient cycling (Huang *et al.,* 2013). Therefore, soil microbial properties have been regarded as important indices reflecting the influences of forest land-use on soils. It has been widely demonstrated that the composition and structure of the microbial community are strongly related to abiotic and biotic factors, such as climate factors (e.g., temperature and precipitation), soil substrate properties (e.g., C and N pools) and tree species composition and diversity (Yin *et al.,* 2016).

Microbial biomass is affected by different land-use types, though consideration of Microbial biomass content shows different land-use rankings when compared to the microbial quotients. This confirms that microbial biomass strongly depends on the content of SOC, and demonstrates that the microbial colonisation of SOC by the total microbial biomass (CFE-MBC) is highest among grasslands, while SOC colonisation by glucose-responsive microbial biomass (SIR-MBC) is highest among the croplands (McGonigle and Turner 2017).

Higher level of microbial biomass is translated into higher SOM mineralization rates at sites with low degradation intensity. In fact, the microbial ratio (MBC/SOC), an indicator of SOM mineralization rate (Wen *et al*., 2014), was higher at these sites. On the contrary, this indicator was lower at sites showing high forest degradation intensity because the soil microbial C pool (MBC) decreases at a faster rate than SOM or because of the lower output from the conversion of substrate material to microbial biomass (Kara and Bolat, 2009).

The presence of dense vegetation can lead to the accumulation of organic matter on the forest floor and can stimulate the populations of soil microorganisms as the microbial biomass is highly dependent upon SOM and overall fertility. Moreover, higher soil moisture contents under dense vegetation might significantly affect the population of soil microbes as soil microorganisms usually respond negatively to low soil moisture (Bing-Cheng and Dong-Xia, 2012).

2.12.1 Soil microbial biomass carbon in forest ecosystem

The terrestrial carbon cycle is provided by photosynthesis and respiratory balance. Carbon fixation by autotrophs, photosynthetic plants, and photo chemotrophic microorganisms allows the transfer of carbon from the atmosphere to the soil. The return of carbon to the atmosphere takes place through the fossil fuels and respiration of microbial and other organisms (Krsashevska *et al.,* 2015). Soil microorganisms utilize carbon sources around the main objectives for growth and proliferation. Therefore, microbes use different forms of organic and inorganic carbon as carbon and energy sources. Due to the role of microorganism activities in the carbon cycle, it interacts directly and indirectly with climate change. For example, organic C mineralization and CO_2 released by respiration increase with increasing temperature. The amount of CO_2 accumulated in the soil increases photosynthesis and release of root exudates (Kooch, Moghimian and Kolb, 2019). This leads to microbial decomposition and respiratory instability. Since soil microorganisms in the carbon cycle have an important role, soil microbial biomass is utilized in most carbon cycle models. Soil microbial activity rate indicates the potential and dynamics of the nutrient cycle in a particular ecosystem (Steinmann *et al.,* 2016). Also, microbial properties of soils can be used as an indicator of any fluctuations in the ecosystem due to its sensitivity to weather conditions, plant species or in the characteristics of animal residues (Brookes *et al*., 1982). The ratio of microbial biomass to total organic carbon might state as an indicator of carbon dynamics in the soil. For example, microorganisms are extremely influenced by anthropogenic effects such as irrigation, fertilization, using insecticide, conventional tillage, etc. (Liebig *et al.,* 2004).

2.12.2 Relationship between soil microbial biomass and soil organic carbon

Soil quality and health indicate the condition of the soil, depending on the chemical, physical, and biological factors that manage the biogeochemical processes of the soil. Some soil properties are rapidly affected by changes in environmental factors; other soil properties, which are not suitable for assessing soil health and quality, change very slowly in a long time (Wang *et al.,* 2012). For instance, some studies have noticed that soil microbial indexes and activity may use more rapid indicators of soil health and quality than the physical and chemical soil properties (e.g., OC and TN). Therefore, soil's biochemical characteristics (e.g., MBC, MBN, Cmic/SOC percentage, Cmic/Nmic ratio, basal respiration, and qCO_2 ratio) respond immediately to environmental stress (Marinari *et al.,* 2006).

SOM decomposition by soil microorganisms plays a crucial role in global carbon and nitrogen cycling. Substrate quality (e.g., lignin, cellulose, hemicellulose content) and the labile C and nutrient availability significantly affect soil microbial decomposition (Schmidt *et al.,* 2011). The availability of nutrient sources affects the decomposition processes by influencing microbial physiology such as the production of extracellular enzyme activities. When there is an insufficient available nutrient or substrate, the microbial production of extracellular enzymes is stimulated (Hernandez and Hobbie, 2010). Winding *et al.* (2005) noticed that soil biogeochemical processes can be determined by organic matter degradation or basal respiration, and it provides an estimation of microbial activity rate.

Soil microorganisms play a predominant role in regulating the conservation and release of SOC (soil organic carbon). Soil microorganisms degrade litter and then allocate the carbon to microbial biomass, exudate carbon as microbial derived organic matter or release carbon by heterotrophic respiration (Manzoni *et al.,* 2012).

Soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial quotient (MBC: SOC ratio) are important indexes of soil quality and soils with higher MBC and MBN contents and higher MBC: SOC ratios could have stronger ability to conserve SOC (Bünemann, 2018). Anderson *et al.* (2010) reported that, the microbial quotient was 2.3% for monoculture soils and 2.9 % for soils under crop rotation. Compared with studies of Deng *et al.* (2016) and Anderson *and* Domsch (2010) it can be shown that MBC: SOC ratios in Mu Us, sandy land was much lower. Lower MBC: SOC ratios indicated that soil microbes were stressed because of lower SOC and MBC contents and higher sand content in soil (Deng *et al.,* 2016).

2.12.3 Factors that affect soil microbial biomass

Soil microbial biomass can be affected by changes of soil water content (SWC), physical and chemical properties (pH, clay and sand content), nutrient status (nitrogen and phosphorus) and quantity and quality of substrates (soil and litter C: N ratio) (Deng, 2016). It was reported that low SWC and lower amount of SOC and litter could lead to a lower amount of soil MBC and MBN content. Previous studies also showed that lower SWC, soil and litter C: N ratios and higher soil total nitrogen (TN) contents could lead to lower MBC: SOC ratios (Serna-Chavez *et al.,* 2013).

2.13 Soil Degradation

Since 1945, it has been estimated that 38% of the cultivated areas in the world have been degraded. Annually, approximately 24 billion tons of topsoil is lost. This is equivalent to about 9.6 million hectares of land (Nanaganoa *et al.,* 2019). Therefore, soil degradation and/or changes in soil quality that result from wind and water erosion, salinization, losses of organic matter and nutrients, or soil compaction are of great concern in every agricultural region in the world (Liu *et al.,* 2006).

Environmental degradation caused by inappropriate land use is a worldwide problem that has attracted attention in sustainable agricultural production systems (Ayoubi *et al.,* 2011). Horel *et al.* (2015) reported that soil formation is a slow process, while soil physical, chemical and biological degradation processes, such as soil compaction, erosion, acidification, decline in organic matter content, etc., can occur relatively fast, especially in areas of agricultural land use. As a result of these faster degradation rates caused by human activities, soil is currently not a sustainable natural resource (Chesworth, 2008) and both short term and long-term consequences need to be addressed to assess and decrease probable soil degradation processes and to preserve soil fertility and healthy soil functioning (Mayer *et al*., 2020).

Forest degradation as a result of changes in socio-economic and environmental conditions is an important issue worldwide and a major component of global change (Parsapour *et al*., 2018). The degradation of forest ecosystems accounts for about 12% of global greenhouse gas emissions. It is important to note that the degradation of soil organic carbon in the tropical ecosystem becomes more serious because of the slow processes of natural fertility restoration. This is due to the fact that most of the soils in the tropics are not resilient, that is, their ability to return to their former condition after being subjected to stresses of land use is very weak (Bonsu et al., 2011).

Soil degradation resulting from storm water runoff and erosion, in many cases, can be exacerbated by removing vegetation, which affects soil water holding capacity, bulk density, porosity, penetrability, and aggregate or particle size distribution (Barto *et al.,* 2010). Degradation and deforestation have impacted negatively on both vegetation and soil carbon stock. Soils in Africa have been reported to lose 136 gigatons of carbon between 1850 and the late 1990s (United Nations Environment Programme, 2012).

It is predicted that there will be severe and widespread droughts globally in the next 30–90 years resulting from either decreased precipitation or increased evaporation (Dai, 2013). These changes are predicted to exacerbate processes leading to land degradation and desertification and a worldwide decrease in soil moisture by 5–15% has been predicted for the 2080–2099 period (Delgado-Baquerizo *et al.,* 2013). Increasing drought could significantly affect many of the biological and chemical processes in wetland ecosystems and the most rapid and prominent change is the modification of microbial community structure and activity (Cao *et al*., 2017).

2.14 Climate change

Climate refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area. Climate varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains or other geographical factors (Cubasch *et al.,* 2013). Climate varies also in time; from season to season, year to year, decade to decade or on much longer time-scales, such as the Ice Ages.

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (UNFCCC, 2011).

Climate in the form of temperature and moisture affects both inputs and losses of organic matter in soils, thus impacting the amount of C stored in the soil, because both temperature and moisture serve as controls to SOC and CO_2 respiration rate (Conant *et al*., 2004). When sufficient water is provided, higher temperatures lead to faster decomposition of soil organic matter, less storage of C in the slow and passive pools, and greater loss of C through respiration (Canadell *et al*., 2007). In warm climates, soil generally contains less organic soil C than in cold climates (Lal, 2007).

Climate change is a serious issue facing the world today. Rising atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) are key contributing factors. Among GHGs, atmospheric CO_2 accounts for 60% of the global warming (Pearson and Palmer, 2000). The concentration of atmospheric CO_2 increased from about 280 parts per million (ppm) by volume prior to 1850, to 395.9 ppm in 2014 (IPCC, 2014). While the increasing concentration of CO_2 is primarily associated with fossil fuel combustion, about 10% of the increase is estimated to be caused by changes in land use, including conversion of forest land for food production (IPCC, 2014).

The problem of climate change and the effects are global; involve cross-cutting issues that affect agricultural production in both the developed and developing worlds. However, the latter is likely to be harder hit than the former because of the stresses on the use of natural resources across a greater variety of agro-ecological zones (Devendra, 2012).

Laderach *et al.* (2011) stated that cocoa growing-areas will lose considerable suitability in Lagunes, Agneby, Moyencomoe and Sud-comoe regions in Côte d'Ivoire by 2030.The climate conditions become more favourable for cashew in the savanna areas. They also predicted that Cocoa will continues to lose suitable area by 2050 as the temperature increases. However, Cashew would be affected positively under predicted climates of 2050 and gains considerable suitable area (Figure 2.4).

The influence of climate change on the suitability of an area for cashews is site-specific. There are areas that will become unsuitable for cashews and where farmers will need to seek alternative crops. These are the Savanes, Denguele and Worodougou regions in Côte d'Ivoire and in the Techiman municipality, located between Sawla-Tuna-Kalba and Bole districts in Ghana (Laderach *et al.,* 2011).

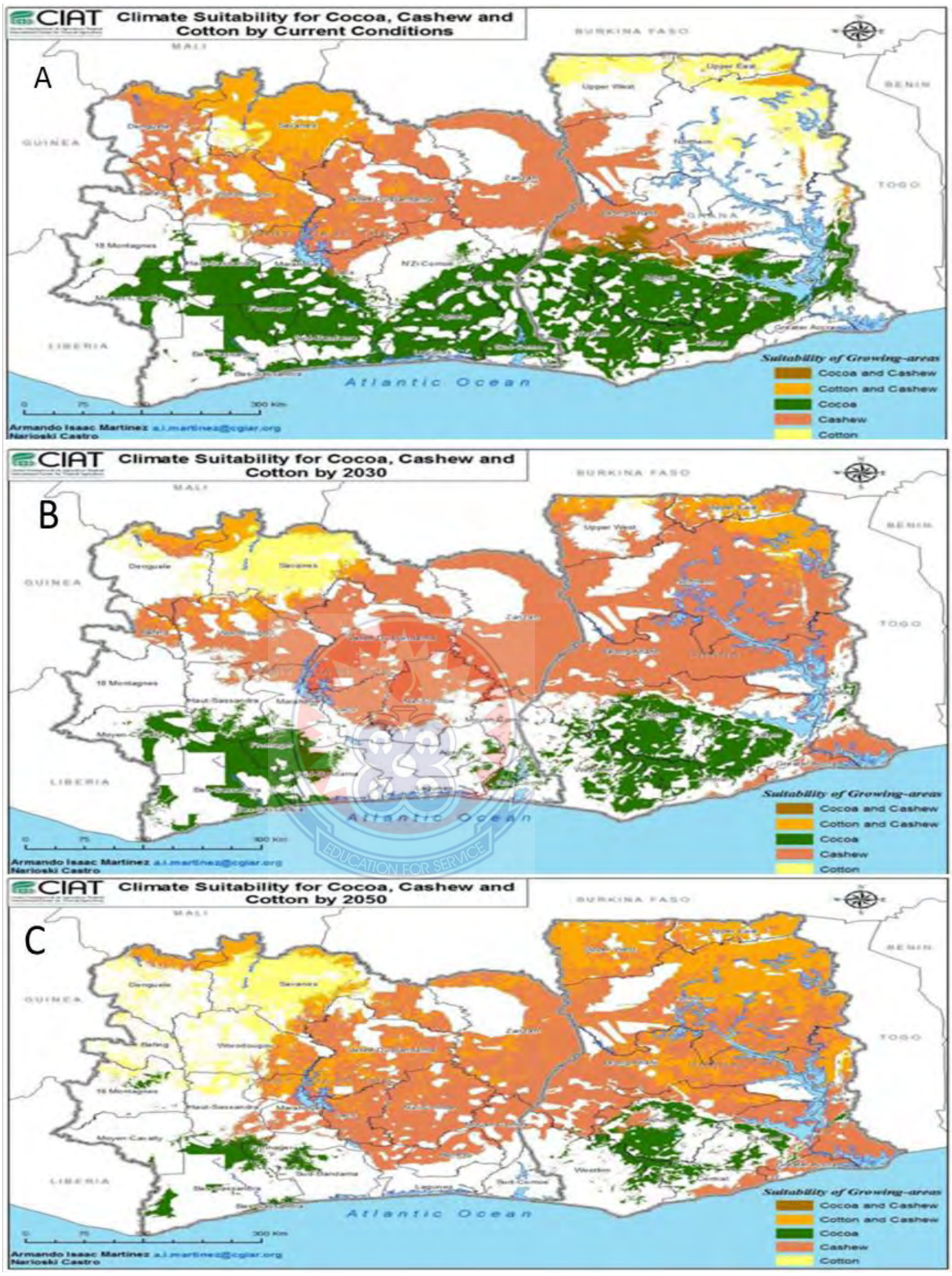

Figure 2. 4 Model Map of climate suitability for cocoa, cashew and cotton in Ghana and Cote D'Ivoire Laderach et al., (2011)

A= Ghana and Ivory Coast's climate suitability for Cocoa, cashew and cotton in current as at 2010

B= Ghana and Ivory Coast's climate suitability for Cocoa, cashew and cotton 2030

C= Ghana and Ivory Coast's climate suitability for Cocoa, cashew and cotton 2050

In contrast, there are areas where suitability for cashew will increase, mainly in the Agneby, N´zi comoe, Moyen comoe and Lacs regions in Côte d'Ivoire and in the Upper East, Upper West, and Northern regions, most of the Brong Ahafo districts and some coastal districts in Ghana (Laderach *et al.,* 2011).

Climate change brings not only bad news but also a lot of increased potential. Cashew production is a good example of the suitable area expanding under the new climatic conditions. This confirms Lobell and Gourdji (2012) assertion that growth rates in aggregate crop productivity will continue to be mainly driven by technological and agronomic improvements, just as they have for the past century. Even in the most pessimistic scenarios, it is highly unlikely that climate change would result in a net decline in global yields (Laderach *et al.,* 2011).

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Site Description

The experiment was carried out at the forest stand, cocoa plantation, coffee plantation, cashew plantation and mango plantation of University of Education, Winneba, Mampong – Ashanti (now AAMUSTED) campus from September 2015 to December 2017. Mampong-Ashanti lies at 457.5 m above sea level and falls within the forest-savannah transitional agroecological zone.

The actual sampling spots of the different land uses are shown in Figure 3.1

FT 1=Forest replication 1
FT 2=Forest replication 2
FT 3=Forest replication 3
FT 4=Forest replication 4
FT 5=Forest replication 5

CE 1=Coffee replication 1
CE 2=Coffee replication 2
CE 3=Coffee replication 3
CE 4=Coffee replication 4
CE 5=Coffee replication 5

MO 1=Mango replication 1
MO 2=Mango replication 2
MO 3=Mango replication 3
MO 4=Mango replication 4
MO 5=Mango replication 5

CA 1=Cocoa replication 1
CA 2=Cocoa replication 2
CA 3=Cocoa replication 3
CA 4=Cocoa replication 4
CA 5=Cocoa replication 5

CW 1=Cashew replication 1
CW 2=Cashew replication 2
CW 3=Cashew replication 3
CW 4=Cashew replication 4
CW 5=Cashew replication 5

Plate 3. 1 Map showing forest stand, cocoa, coffee, cashew and mango plantations

Climate

Rainfall distribution in the area is bimodal and classified into major and minor seasons. The major season commences from March to July and the minor season from early September to late November (Mampong, Metrological Station, 2018). The average annual rainfall ranges between 1270 mm and 1525 mm with a monthly mean rainfall ranging between 105 mm and 127 mm. The monthly day temperature is about 25-32 ºC.

Soil and Vegetation

The soil type at the project site can be described as 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 Bediesi series known as Chromic Luvisol (FAO/UNESCO, 1990) and derived from the voltaian sandstone (Soil Research Institute, 1989). 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.

3.2 Experimental design and treatment

The experiment was a 5 × 6 factorial laid in a Randomised Complete Block Design with 5 replications. There were 5 different land uses and 6 sampling seasons as shown below:

Table 3. 1 Table indicating the 5 land uses and 6 sampling seasons

Land Uses	Season
FT=Forest	DS2016 = 1st Dry season (December 2015 - February2016)
CA=Cocoa	MRS2016 =1st Major rain season (March 2016 - July 2016)
CE=Coffee	MNRS2016 = 1st Minor rain season (September 2016- November 2016)
CW=Cashew	DS2017 = 2nd Dry season (December 2016 - February2017)
MO=Mango	MRS2017 = 2nd Major rain season (March 2017 - July 2017)
	MNRS2017 = 2nd Minor rain season (September 2017 - November 2017)

3.2.1 Land use

This are the different uses of land that has been converted from an intact forest or the intact forest itself: forest, cocoa, coffee plantation, cashew and mango plantation.

3.2.1.1 Forest stand

This was an intact or virgin forest stand with different species of trees. Basically, all other land uses in the University were developed from it. It currently surrounds the school plantations and goes as far as Kyremfaso (Plate 3.2). The forest stand covers an area of about 120 acres. The land use has never been changed for any other purpose and remain virgin forest. The Tatafro stream runs through the forest.

Plate 3.2 A picture of the Natural Forest

The sampling spots for forest stand were N7.082600 W-1.396818 355 m; N7.082812 W-1.397628 355 m; N7.082070 W-1.397592 367 m; N7.079778 W-1.398082 368 m and N7.079407 W-1.3981137 372 m for spots FT1, FT2, FT3, FT4 and FT5 respectively.

3.2.1.2 Cocoa plantation

This was a 21-year-old cocoa farm planted at a 3 m by 3 m planting distance with no shade trees (Plate 3.3). The management practices administered on the cocoa plantation were the bi-weekly application of fungicides and insecticides from April to November each year, fertilizer application at COCOBOD recommended rate during June and July each year. Harvesting was done twice (thus September to December and February to April).

Plate 3.3 A picture of the Cocoa plantation

The sampling spots for cocoa plantation were N7.081095 W-1.395772 375 m; N7.081540 W-1.395908 3371 m; N7.080870 W-1.397057 373 m; N7.080660 W-

1.396383 378 m and N7.081933 W-1.397098 370 m for spots CA1, CA2, CA3, CA4 and CA5 respectively.

3.3.1.3 Coffee plantation

The 21-year-old coffee plantation sits on a 10-acre land (Plate 3.4). The coffee plantation also experienced some regular management practices like weed control, fertilization and disease and pest control. Harvesting of coffee was done in February and March.

Plate 3.4 A picture of the Coffee plantation

The sampling spots for coffee plantation were N7.080045 W-1.397000 376 m; N7.080091 W-1.396800 377 m; N7.080367 W-1.396578 377 m; N7.080431 W-1.396838 376 m and N7.080660 W-1.396383 378 m for spots CE1, CE2, CE3, CE4 and CE5 respectively.

3.3.1.4 Cashew plantation

The cashew plantation was about 20 years old and sits on a 10-acre land (Plate 3.5). Periodic disease and pest control were done in the cashew farm. This was normally done within November and January, while foliar fertilizer applications were also done. Harvesting of cashew nuts were done within February and mid-March.

Plate 3.5 A picture of the Cashew plantation

The sampling spots for cashew plantation were N7.080735 W-1.395200 379 m; N7.080833 W-1.394873 378 m; N7.080652 W-1.394493 379 m; N7.081040 W-1.394590 381 m and N7.081033 W-1.395125 375 m for spots CW1, CW2, CW3, CW4 and CW5 respectively.

3.3.1.5 Mango plantation.

Mango plantation, the youngest of all the plantation was 13 years old and sit on an acre of land. The basic management practice for the mango plantation was disease and pest control (October to November) and periodic fertilization. The plantations were protected from bush fire with fire belt. Although, pruning was periodically done in all the different plantations, pruning was not done within the period of the research.

Plate 3.6 A picture of the Mango plantation

The sampling spots for mango plantation were N7.09302 W-1.397282 374 m' N7.079530 W-1.397360 373 m; N7.079442 W-1.397540 376 m; N7.079337 W-1.397693 375 m and N7.079545 W-1.397785 370 m for spots MO1, MO2, MO3, MO4 and MO5 respectively.

3.4 Assessment of Soil Physical Properties

3.4.1 Particle size analyses

The hydrometer method (Klute, 1986) was used in the determination of the particle size. This method was used because it allows for the non-destructive sampling of suspensions undergoing settling and also, provides for multiple measurements on the same suspension so that detailed particle-size distribution can be obtained with minimum effort. Fifty-one grams (51 g) of air-dried soil from each plot were weighed into milk-shake cup bottles. Ten millilitres (10 ml) of 5% Calgon (Sodium hexametaphosphate) alongside with 100 ml of distilled water were added to the soil. The Calgon served as a dispersing agent for the soil particles.

The mixture was shaken with a mechanical shaker for twenty (20) minutes and the content was poured into a 1000 ml measuring cylinder, the milk-shake bottle cap was rinsed with distilled water and added to the content to reach the 1000 ml mark. The cylinder with the content was shaken to distribute the particles equally throughout the suspension and first hydrometer and temperature readings were taken after 40 seconds. The suspension was left to stand for three (3) hours to allow the soil particles to settle. Hydrometer and temperature readings were taken after three hours and the percent fractions of each soil component was calculated as follows:

$$\%\,\boldsymbol{Sand} = \mathbf{100} - [\boldsymbol{H_1} + \mathbf{0.2}(\boldsymbol{T_1} - \mathbf{20}) - \mathbf{2}] \times \mathbf{2} \qquad (\mathbf{1})$$

$$\%\,\boldsymbol{Clay} = \boldsymbol{H_2} + [\mathbf{0.2}(\boldsymbol{T_2} - \mathbf{20}) - \mathbf{2}] \times \mathbf{2} \qquad \mathbf{(2)}$$

$$\%\,\boldsymbol{Silt} = \mathbf{100} - (\%\,\boldsymbol{Sand} + \%\,\boldsymbol{Clay}) \qquad (\mathbf{3})$$

Where, H_1 is the first hydrometer reading after 40 seconds; H_2 is the second hydrometer reading after three hours, T_1 is the first temperature reading after 40 seconds and T_2 is the second temperature reading after three hours. The textural class was determined using the textural triangle.

3.4.2 Bulk density (ρ_b)

Bulk density is defined as the mass (weight) of a unit volume of dry soil. The dry bulk density was determined from soil cores collected on the field with core sampler (Klute, 1986). It was determined for 0-15 cm depth which is within the zone of active root activity for most food crops grown on the plots. A cylindrical metal sampler (core sampler) with a diameter of 5.1 cm and a height of 10 cm was driven into the soil vertically with the aid of wooden plank and a mallet to fill the sampler. In order to prevent compression of the soil, another cylinder of equal diameter was placed directly on top of the sampling cylinder. The sampler and its contents were then removed carefully to maintain the natural structure and packing of the soil. Soils that extended beyond the sampler were trimmed with a sharp knife and the volume of the soil was taken to be the same as the volume of the cylinder. The cylinders were covered with polythene bag and sent to the laboratory and oven dried at 105ºC for 24 hours to a constant mass. The oven dried soils were weighed and the dried bulk densities were calculated by dividing the oven dried mass (M_s) by the total volume of the soil (V_t). The volume (Vt) of soil sample taken was derived from the relation:

$$\boldsymbol{VT = \pi r^2 h} \qquad (4)$$

Where, π = 22/7, r = inner radius (cm) of the cylindrical core sampler, h = height (cm) of the cylindrical core sampler

Thus, the dry bulk density was calculated from the formula:

$$\boldsymbol{\rho_b} = \left(\frac{\boldsymbol{M_s}}{\boldsymbol{V_t}}\right) \qquad (5)$$

3. 4.3 Total porosity (f)

Total porosity is the volume percentage of the total bulk density of the soil not occupied by solid particles. Total porosity was calculated by the formula (Hillel, 1982);

$$\boldsymbol{f} = \mathbf{1} - \left(\frac{\boldsymbol{\rho_b}}{\boldsymbol{\rho_s}}\right) \qquad (\mathbf{6})$$

Where, f is total porosity, ρ_b is bulk density and ρ_s is particle density (assumed to be 2.65 g/cm^3 for mineral soils).

3. 4.4 Aeration porosity (ξ_a)

Soil aeration porosity is the proportion of space in total porosity that is occupied by air. Soil aeration porosity was calculated from the formula (Klute, 1986):

$$\xi_a = \boldsymbol{f} - \theta_v \qquad (\mathbf{7})$$

Where, ξ_a is aeration porosity, f is the total porosity and θ_v is volumetric water content.

3. 4.5 Void ratio (e)

Soil void ratio is the ratio of the volume of air and water to the total volume of solids. Soil void ratio was calculated from the formula (Klute, 1986):

$$\boldsymbol{e} = \frac{\boldsymbol{f}}{\mathbf{1}-\boldsymbol{f}} \qquad (\mathbf{8})$$

Where, e is void ratio, f is the total porosity

3. 4.6 Moisture content

Soil moisture is the amount of moisture left in the soil after field capacity. Soil water content was determined on volume basis. 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 downward movement of water has materially ceased, which is attained in the field after 48–72 hours of saturation (Veihmeyer and Hendrickson, 1931; USDA-NRCS, 2008). Soil samples were collected with a core sampler and sent to the laboratory where they were weighed to find their initial masses. They were then oven-dried at a temperature of 105°C to a constant mass M_s. The loss of water upon drying constituted the mass of water M_w contained in the sample. Moisture content was determined on volume basis (Hillel, 1982)

$$\boldsymbol{\theta_v = \theta_g \times \left(\frac{\rho_b}{\rho_w}\right)} \qquad (9)$$

Where, $\theta_g$is the gravimetric moisture content, $\rho_b$is the dry bulk density and $\rho_w$is the density of water (assumed to be 1.0 g/cm^3).

$$\boldsymbol{\theta_g = \left(\frac{M_w}{M_s}\right)} \qquad (10)$$

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

$$\boldsymbol{M_w = M_t - M_S} \qquad (11)$$

Where M_t is total mass of moist in soil.

3.4.7 Degree of saturation

Degree of saturation is the percentage all pores that are filled with water in the soil. The soil degree of saturation was calculated from the formula:

$$\boldsymbol{\theta_s = \frac{\theta_v}{f} \times 100} \qquad (12)$$

Where, θ_s is degree of saturation,$\boldsymbol{\theta_v}$is volumetric moisture and (f) is total porosity

3.4.8 Aggregate stability (ASt)

Aggregate stability is the ability of soil particles to resist breakage caused by rain droplets. The modified wet sieving method (Kemper and Rosenau, 1986) was used in the determination of the stability of soil aggregates for each spot and depth (0-15cm). Soil samples from each spot and depth were collected with a spade into aluminium containers and air dried in the laboratory. The aggregate sizes between 2 mm to 4 mm were prepared by sifting the dried aggregates through 4mm and 2mm sieve. Twenty grams (20 g) of the aggregates were weighed unto a 0.25 mm sieve. The aggregates were wetted with an atomizer spray. The sieve was immersed in water contained in a basin and gently rotated 50 times. It was ensured that the aggregates on the sieve were totally covered with water. The wet sieved aggregates were emptied into Pyrex beaker and oven dried at 105ºC for 24 hours to a constant mass (*M*). Another 20 g sample was weighed and oven dried at 105ºC for 24 hours to a constant mass (*m*). After oven drying, the wet sieved aggregates were divided by the sub sample to give the aggregate stability, which was expressed as a percentage, aggregate stability calculated as follows: $\boldsymbol{Ast} = \left(\frac{M}{m} x\ 100\right) \quad (13)$

3.5 Assessment of Soil Hydrological and Hydraulic Properties

3.5.1 Field infiltration (I)

Infiltration is the amount of water that enters the soil from the surface per unit area. A study on the infiltration was conducted in the field using the single ring infiltrometer (Klute, 1986). Before the infiltration measurements were made, soil samples were taken to determine the moisture content of the soil at each spot. A cylindrical infiltrometer of 10 cm diameter and height of 30 cm was driven into the soil to a depth of 15 cm with the aid of a wooden plank and a mallet. The soil surface was mulched with plant debris (dry grass and leaves) to prevent the disturbance of soil surface (dispersion and clogging of soil pores) and false measure of infiltration amount when the soil surface in the infiltrometer was instantaneously ponded with water. A constant water head of 5 cm from the soil surface was maintained in the cylinder with water from a 1000 ml (1 litre) glass measuring cylinder (Plate 3.7). The volume of water that was used to maintain a constant head of 5 cm in the infiltrometer in a chosen time was used as a representation of the amount that entered the soil at the stipulated time.

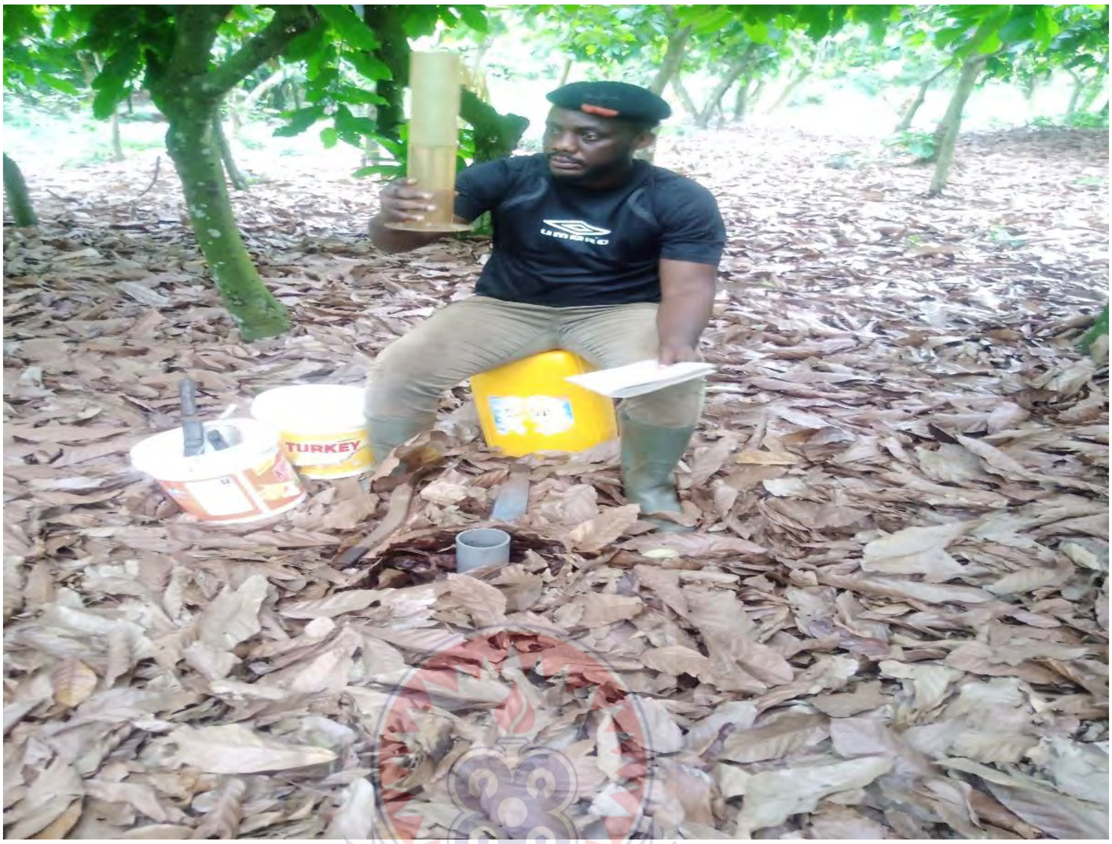

Plate 3.7 Researcher measuring infiltration amount using the single ring method

The vertical infiltration was measured from the cylinder for a period of 60 minutes for each spot. The initial infiltration was measured at 30 seconds interval for the first five minutes when infiltration was very fast after which the interval was increased to 60, 180 and 300 seconds respectively as infiltration slowed down over time towards the steady state.

3.5.2 Infiltration rate (i)

Infiltration rate is the amount of water that enters the soil per unit time. The cumulative infiltration amounts (I) were plotted as a function of time for each spot on a linear scale. The slopes of the cumulative infiltration amounts taken at different time scales represented the infiltration rates (i).

3.5.3 Steady state infiltrability (Ko)

The infiltration rates were plotted against time and the steady state infiltrability (K_o) was obtained at the point where the infiltration rate curve became almost parallel to the time axis.

3.5.4 Sorptivity (S)

This is the measure of the ability of the soil to absorb water. It is an important parameter in the description of both cumulative and instantaneous infiltration. It also controls or is responsible for the initial state of infiltration. Plots of Cumulative infiltration amount (I) as function of the square root of time ($t^{1/2}$) for the first five minutes were performed and sorptivity (S) was obtained from the slope of each plot. Sorptivity was measured by dividing the first 5-minute cumulative infiltration by the square root of the time (Philip, 1957).

$$I = St^{\frac{1}{2}} + Kot \qquad (14)$$

Where I is Cumulative infiltration, S is Sorptivity and Kot is stead head gradient.

Note at 5-minutes Kot is assumed to be zero (0), therefore at 5-minute

$$I = St^{\frac{1}{2}} \qquad (15)$$

Therefore, Sorptivity is

$$S = \frac{I}{t^{1/2}} \qquad (16)$$

3.5.5 Saturated hydraulic conductivity (K_s)

Saturated hydraulic conductivity is the ability of a soil to transmit water within it at saturated conditions. The saturated hydraulic conductivity (K_s) measurements were made on the cores in the laboratory using the falling head permeameter method similar to that described by Bonsu and Laryea (1989). In the measurement, core samples were obtained for each spot from the 0-10 cm and 10-20 cm depths. The cores were soaked for 24 hours in water until they were saturated. A large empty can with perforated bottom was filled with fine gravel. The core was placed on the gravel supported with a plastic sieve. The whole system was placed over a sink in the laboratory and water was gently added to give hydraulic head in the extended cylinder. The fall of the hydraulic head H_t at the soil surface was measured as a function of time t using a water manometer with a meter scale. Saturated hydraulic conductivity was calculated by the standard falling head equation as:

$$K_{s=}\left(\frac{aL}{At}\right).ln\left(\frac{H_o}{H_t}\right); \qquad (17)$$

Where, a is the surface area of the cylinder, A is the surface area of the soil, H_o is the initial hydraulic head, H_t is the final hydraulic head and L is the length of the soil sample. By rewriting equation **(17),** a regression of $ln\left(\frac{H_o}{H_t}\right)$on t with slope $b =$ $K_s\left(\frac{A}{La}\right)$was obtained. Since $a = A$ in this particular case, K_s was simply calculated as:

$$K_s = bL \qquad (18)$$

3.6. Soil carbon pool measurements

3.6.1 Carbon stock

Carbon stocks computations was conducted for the soil as described by Batjes (1996),

Soil carbon stock (SCS) (0-15cm) was calculated as:

$$SCS = \mathrm{SOC} \times \rho\mathrm{b} \times \mathrm{Z} \qquad (19)$$

Where:

SOC = soil organic carbon content, Z = soil depth or the thickness of the soil horizon, ρb = bulk density

3.6.2 Conversion of soil organic carbon to CO_2 (Carbon Sequestration)

To convert soil organic carbon to CO_2, the fraction of soil organic carbon relative to the amount of soil was multiplied by the bulk density of the soil and the depth from which the samples were taken and converted to kilogram per hectare. The final result was multiplied by a factor of 44/12 (i.e. molecular weight of CO_2/atomic mass of C) to convert the carbon to carbon dioxide (Donovan, 2013).

$$SCS = \mathbf{SOC} \times \boldsymbol{\rho}\mathbf{b} \times \mathbf{Z} \times \frac{44}{7} \qquad \textbf{(20)}$$

3.7 Soil Chemical Properties Analyses:

3.7.1 Determination of soil pH

pH is the negative logarithm of hydrogen ion concentration.

$$pH = log\frac{1}{[H+]}$$

The pH was measured potentiometrically which is in equilibrium with soil suspension (Chapman and Pratt, 1961). The apparatus used were: glass electrode and pH meter beaker, 2 mm sieve, air-dried sample of soil and a glass rod. Regents used were: distilled water, potassium chloride, calcium chloride, buffer solution. A 20g weight air-dried soil was passed through 2 mm sieve and put into a 100 ml 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 suspension and when the reading had stabilized, the pH was measured.

3.7.2 Determination of soil organic carbon (soc)

The Walkley-black method was employed. Reagents used were: potassium dichromate, cone, sulphuric acid, orthophosphoric acid, ortho phenanthroline, barium diphenylamine sulfonate and ferrous sulphate. The representative sample was ground to pass through 0.5mm sieve. This was later weighed and transferred into 250ml Erlenmeyer flask. Ten (10 ml) of 0.1667 M (IN) $K_2Cr_2O_7$ solution was added from a burette into each flask and swirled gently to disperse the soil. Twenty (20 ml) of

Concentration H_2SO_4 was also added using an automatic pipette, directing the stream into suspension.

The flask was immediately swirled gentle 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 indicator was added and titrated with 1M $FeSO_4$ solution. As the end point was approached, the solution took on a greenish cast and then changed to dark green. Then 0.5 ml $K_2Cr_2O_7$ 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):

$$\% \boldsymbol{Organic\ C} = \frac{\boldsymbol{M} \times (\boldsymbol{V1} - \boldsymbol{V2})\ \boldsymbol{x}\ \mathbf{0.003}\ \boldsymbol{x}\ \mathbf{1.33}\boldsymbol{x}\mathbf{100}}{\textbf{g of air}-\textbf{dry soil}} \qquad \mathbf{(21)}$$

$$= \frac{\boldsymbol{M\ x}\ (\boldsymbol{V1} - \boldsymbol{V2})\ \boldsymbol{x}\ \mathbf{0.39}\ \boldsymbol{x\ mcf}}{\boldsymbol{S}} \qquad \mathbf{(22)}$$

Where: M = molarity of ferrous sulphate solution for blank titration, V1 = 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)

Percentage organic matter was determined by the conversion of organic carbon to organic matter with the empirical factor 1.724: % Organic matter = 1.724 $\boldsymbol{x}$ % organic carbon (1.724 is the Van Bemellen Factor for mineral soils)

3.7.3 Determination of 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 hours. The tubes in the Kjeldahl flask were put in the rack and heated at 100 °C for at least 2 hours. The tubes were removed and allowed to cool. Three (3) aliquots of 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 250 ml 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:

$$\%\boldsymbol{N} = \frac{(\boldsymbol{a} - \boldsymbol{b})\boldsymbol{x}\ \boldsymbol{M}\ \boldsymbol{x}\ \mathbf{1.4}\ \boldsymbol{x}\ \boldsymbol{mcf}}{\boldsymbol{S}} \times \frac{\boldsymbol{V}}{\boldsymbol{t}} \qquad (\mathbf{23})$$

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, V = Total volume of digest, t = volume of aliquot taken for distillation, mcf = moisture correction factor, 1.4 = 14 x 0.001 x 100% (14 = atomic mass of nitrogen)

3.7.4 Determination of available phosphorus (P)

Soil available phosphorus was determined using the Bray P1 method (Olsen and Sommers, 1982). Two grams of air-dried soil was weighed into a 50 ml shaking bottle. Twenty millilitres (20) ml of Bray^{-1} solution was added as an extracting agent and the mixture shaken for ten minutes, and then filtered through Whatman No. 42 filter paper. Ten millilitres (10 ml) of the filtrate was pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent added for colour development. The absorbance was measured at 660 nm wavelength on a spectronic 21D spectrophotometer. The concentration of P was obtained from a standard curve.

$$\mathbf{P}\left(\frac{\mathbf{mg}}{\mathbf{kg}}\right) = \frac{(\mathbf{a}-\mathbf{b}) \times \mathbf{20} \times \mathbf{10} \times \mathbf{mcf}}{\boldsymbol{w}} \qquad (\mathbf{24})$$

Where: a = mg/l P in sample extract, b = mg/l P in blank, w = sample weight in gram, mcf = moisture correction factor, 20 = volume of extracting solution, 10 = final volume of sample solution

3.7.5 Determination of available potassium (K)

The flame photometric method described by Soil Science Society of Ghana (2009) was used. Appropriate aliquots of standard samples digest and blank were taken. K-emission in an air-propane flame at 768 nm wavelength was measured. The concentration of K was calculated as:

$$\% \boldsymbol{K} = \frac{(\boldsymbol{a}-\boldsymbol{b})\ \boldsymbol{x}\ \boldsymbol{m}}{\boldsymbol{factor}} \qquad (\mathbf{25})$$

Where a = measured mgK/ ml in samples, b = measured mgK/ ml in blank,

m = moisture correction factor, factor = $\frac{200}{Dilute\ factor}$

3.7.6 Determination of calcium and magnesium

The 1.0 M ammonium acetate extract as described by Black (1986) was used to determine the exchangeable bases (calcium, magnesium,) in the soil. A 25 ml aliquot of the extract was transferred into an Erlenmeyer flask to analyse for magnesium and calcium. One (1) ml of 2.0 % potassium cyanide, one (1) ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added to one (1) ml portion of hydroxylamine hydrochloride. This followed with the titration of the solution with 0.01 M EDTA (ethylene diamine tetra acetic acid) until a pure turquoise blue colour was obtained.

3.7.7 Determination of calcium only

Distilled water was used to make up a volume up to 50 ml of a 25 ml aliquot of the extract after the extract was transferred into a 250 ml Erlenmeyer flask. One (1) ml hydroxylamine, one (1) ml of 2.0 % potassium cyanide and one (1) ml of 2.0 M potassium ferrocyanide solution were added to it. Few minutes were allowed after which 5 ml of 8.0 M potassium hydroxide solution and a spatula of murexides indicator were added. The resultant solution was titrated using 0.01 M EDTA solution to obtain a pure blue colour.

Calculation:

$$\text{Ca} + \text{Mg (or Ca) (cmol/kg soil)} = \frac{\mathbf{0.01 \times (\mathit{Va} - \mathit{Vb}) \times 1000}}{\boldsymbol{w}} \qquad \mathbf{(26)}$$

where

w = weight (g) of air – dried soil used, Va = ml of 0.01 M EDTA used in sample titration, Vb = ml of 0.01 M EDTA used in in blank titration, 0.01 = concentration of EDTA

3.8 Soil microbial biomass analysis

3.8.1 Soil microbial biomass carbon and nitrogen

The method of chloroform fumigation and extraction (FE) as described by Ladd and Amato (1989) was used to determine the microbial biomass. Ten grams field - moist soil sample, after passing through a 4 mm mesh, was put in a crucible and placed in a desiccator. A shallow dish containing 30 ml of alcohol -free chloroform was placed by it. A crucible containing a control sample (10 g) was placed in a separate desiccator without chloroform. The desiccators were covered and allowed to stand at room temperature for 5 days (Anderson and Ingram, 1998). Immediately after fumigation, 50 ml of 0.5 M K_2SO_4 solution was added to the soil samples to extract microbial carbon and nitrogen from the lysed microorganisms. Total nitrogen in the extract was then determined by the Kjeldahl method. The amount of microbial carbon in the extract was determined using the colorimetric method. An aliquot (5 ml) of the extract was pipetted into 250 ml Erlenmeyer flask. To this were added 5 ml of 1.0 N (0.1667 M) potassium dichromate and 10 ml on cent rated sulphuric acid. The resulting solution was allowed to cool for 30 minutes after which 10 ml of distilled water was added. A standard series was developed concurrently with carbon concentrations ranging from 0, 2.5, 5.0, 7.5, 10.0 mg/ml C. These concentrations were obtained when volumes of 0, 5, 10, 15 and 20 ml of a 50 mg/ml C stock were pipetted into labelled 100 ml volumetric flasks and made up to the mark with distilled water. The absorbances of the standard and sample solutions were read on a spectronic 21D spectrophotometer at a wavelength of 600 nm. A standard curve was obtained by plotting absorbance values of the standard solutions against their corresponding concentrations. Extracted carbon concentration of the samples was determined from the standard curve. For biomass C and N calculations, k -factors of 0.35 (Sparling *et al*., 1990) and 0.45 (Ross and Tate, 1993) were used, respectively.

The following equations according to Sparling and West (1998) were used to estimate the microbial C and N from the extracted C and N respectively:

$$\boldsymbol{Microbial\ C\ (mg) = \frac{Ec}{k}} \qquad \textbf{(27)}$$

$$\boldsymbol{Microbial\ N\ (mg) = \frac{EN}{K}} \qquad \textbf{(28)}$$

Microbial N (mg) = E_N /k where

E_N = the extracted nitrogen produced following fumigation

E_C = the extracted carbon produced following fumigation

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

3.8.2 Soil microbial biomass phosphorus

For microbial biomass P analysis, 5 g of field-moist soil was weighed into a crucible and fumigated in a desiccator with 30 ml of alcohol-free chloroform for 5 days. Both fumigated and unfumigated soil samples were shaken with 35 ml Bray's No.1 extracting solution (0.03 M NH_4F+ 0.025 M HCl) for 10 minutes and filtered. Correction for adsorption of P during fumigation was made by simultaneously equilibrating unfumigated soil with a series of P containing standard solutions followed by extraction with the Bray-1 solution. The amount of chloroform released P was determined according to the relationship between P added (from standard solutions or microbial lysis) and P extracted by the Bray-1 solution (Oberson *et al*., 1997). Phosphorus adsorption during equilibrium is described by the following equation according to Barrow and Shaw (1975) and adapted by Morel *et al*. (1997):

$$Extp = Ext0 + b1Pad^{b2} \qquad \textbf{(29)}$$

where

Extp = Pi concentration (mg/l) extracted after equilibration with different amounts of P added, Ext0 = Pi concentration extracted without P addition, b1, b2 = coefficients estimated by non- linear regression of mean values of Extp against Pad, Pad = amount of P added (0 - 20 mg/kg) Chloroform released P corresponds to a P addition and is calculated from the equation:

$$Pchl. = [(Extchl - Ext0)/b1]^{1/b2} \qquad \textbf{(30)}$$

where Pchl. = chloroform released P (mg/kg), Extchl = Pi concentration in extracts of fumigated samples. The amount of microbial P is estimated by assuming a kp factor of 0.4 (Brookes et al., 1982; McLaughlin and Alston, 1986).

3.8.3 Soil microbial biomass carbon, nitrogen and phosphorus quotient

Microbial quotient is the ratio of microbial biomass to soil organic carbon and indicates how efficiently soil organic matter is being used by microorganisms.

3.8.3. 1 Determination of microbial biomass carbon quotient

$$qCmic = \left(\frac{Cmic}{SOC} x\ 100\right) \qquad (31)$$

Where

qC_{mic} = *soil microbial biomass qutient carbon,* C_{mic} = *soil microbial biomass carbon and C= soil organic carbon*

3.8.3. 2 Determination of microbial biomass nitrogen quotient

$$qCmic = \left(\frac{Nmic}{N} x\ 100\right) \qquad (32)$$

Where

qN_{mic} = *soil microbial biomass qutient nitrogen,* N_{mic} = *soil microbial biomass nitrogen and N= soil total nitrogen*

3.8.3. 1 Determination of microbial biomass carbon quotient

$$qCmic = \left(\frac{Pmic}{P} x\ 100\right) \qquad (33)$$

Where

qP_{mic} = *soil microbial biomass qutient phosphorus,* P_{mic} = *soil microbial biomass phosphorus and P= soil available phosphurus*

3.9 Litter harvest

A $2.25m^2$ jute sheet was spread on the floor of each of the experimental plots. It was secured by placing some weight on them. In addition, the four corners of the sheets were tired to the base of the trees with a rope. The litter that had fallen on the jute sheets were collected and weighed every two weeks of the research (within the distinct seasons).

3.10 Statistical analyses

The data obtained were subjected to ANOVA (analysis of variance) using GenStat statistical package (12th edition). Means were separated using the least significant difference (LSD) method at 5% level of probability. In addition, the R software (R Core Team, 2016) was utilized in fitting linear regression, correlation and to plot box plot for land use, season and land use and season interaction graphs.

CHAPTER FOUR

4.0 RESULTS

4.1 Climatic conditions and initial soil properties at the experimental site

4.1.1 Three-year climatic conditions of the experimental site during the research

The mean monthly climatic condition for the three-year experimental period of the study sites is presented in Figure 4.1 below.

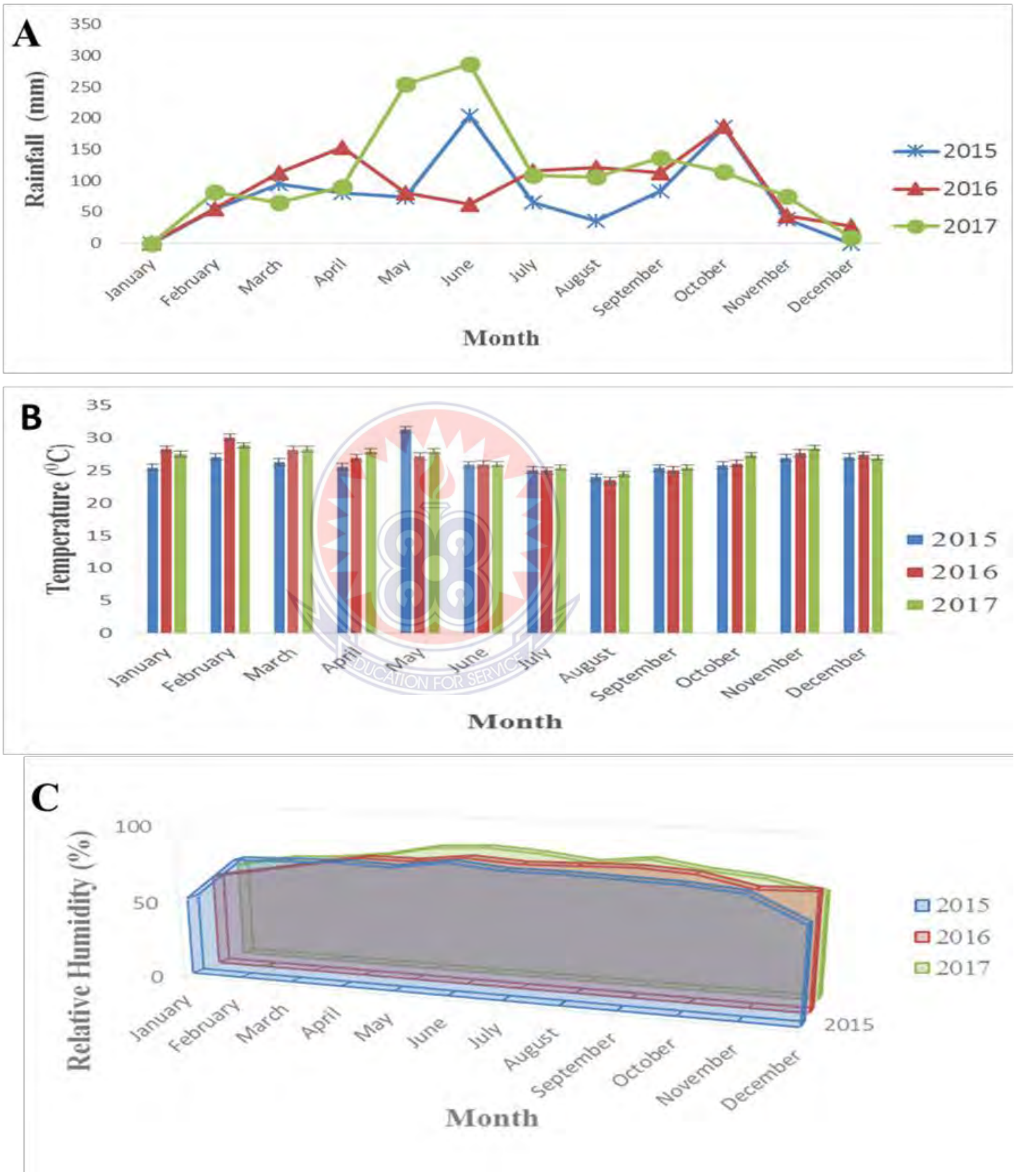

Figure 4. 1 Climatic conditions of the experimental site during the research

A=Monthly rainfall mean for the three-year period, B=Monthly temperature mean for the three-year period, C=Monthly relative humidity means for the period

From Figure 4.1.a, it could be observed that the months of May and June of the years 2015 and 2016 recorded relatively lower amount of rainfall, although they were expected to be the peak months of rainfall during the major rain season. This was translated into the highest temperature recordings in the month of May in the year 2015, which evidently was the highest monthly temperature recorded in the three-year period of the current study (Figure 4.1b).

The low rainfall amounts recorded within the months of May and June of 2015 and 2016, coupled with the high temperature resulted in the lowest relative humidity recording within the same period (Figure 4.1c).

4.1.2 Seasonal rainfall, temperature and relative humidity

Figure 4.2 illustrates the seasonal mean values of rainfall, temperature and relative humidity of the experimental site. It was observed that the highest temperatures were recorded in DS2016 (28.5 ºC) and DS2017 (27.9 ºC), while the least temperature values were recorded in MNRS2016 (26.3 ºC) and MNRS2017 (27.1 ºC).

As expected of a dry season, DS2016 (18.8 mm) and DS2017 (36.4 mm) had the lowest rainfall amounts while MNRS2016 (114.5 mm) and the MRS2017 (161.1 mm) had the highest values in 2016 and 2017, respectively. The MRS2017 (79 %) had the highest relative humidity, while DS2016 (62 %) had the least.

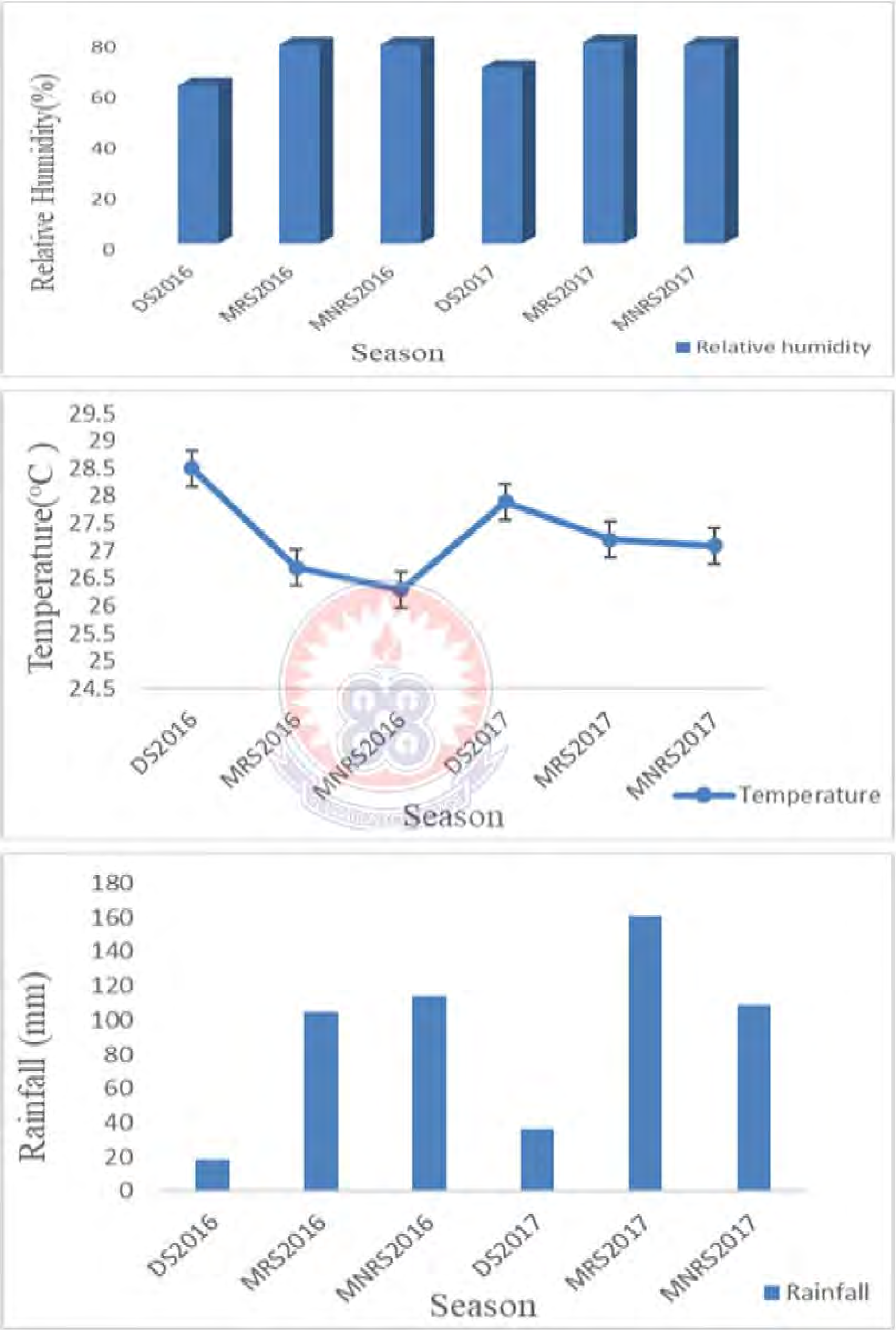

Figure 4. 2 Mean rainfall, temperature and relative humidity for Ds (2016, 2017), MRS (2016, 2017), MNRS (2016, 2017)

It was observed that the rain seasons recorded similar relative humidity values MRS2016 (78 %), MNRS2016 (78 %) and MRS2017 (79 %), MNRS2017 (78 %). Thus, DS2016 and DS2017 recorded the lowest relative humidity values in each year (Figure 4.2).

4.1.3 Initial soil properties of the different land uses

The initial tree litter fall, soil physical, hydraulic and hydrological properties of the different agricultural land uses are presented in Table 4.1

Table 4. 1 Initial litter fall, physical, hydraulic and hydrological properties of the different land uses

	Forest	**Cocoa**	**Coffee**	**Cashew**	**Mango**
Physical properties					
Bulk density (ρ_b (g cm^{-3}))	1.35	1.37	1.41	1.47	1.5
Gravimetric moisture content (θ_g (g/g))	10.42	12.75	11.98	14.45	11.08
Volumetric moisture content (θ_v (cm^3/cm^3))	14.07	17.47	16.89	21.24	16.61
Total porosity (*f* (%))	49.06	48.30	46.79	44.53	43.40
Aeration Porosity (ξ_a (%))	34.99	30.83	29.90	23.28	26.78
Aggregate stability (*ASt* (%))	76.26	68.94	64.21	74.58	55.4
Sand *(%)*	81.18	72.38	77.98	76.38	73.18
Clay *(%)*	11.48	13.08	11.48	11.08	10.28
Silt *(%)*	7.34	14.54	10.54	12.54	16.54
Textural class	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Hydraulic and hydrological properties					
Cummulative infiltration amount (*I* (mm))	191.47	15.59	150.08	69.58	27.56
Infiltration rate (*i* (mms^{-1}))	0.053	0.004	0.042	0.019	0.008
Sorptivity (*S* (mm s$^{-1/2}$))	1.154	0.2291	0.895	0.417	0.183
Steady state infiltrability (K_o (mm s^{-1}))	0.054	0.004	0.043	0.019	0.008
Saturated hydraulic conductivity (K_s (mm s^{-1}))	0.081	0.007	0.064	0.029	0.012
Litter fall (t/ha)	3.14	2.48	2.95	3.867	1.465

4.1.3.1 Forest stand (Reference point)

The forest stand soil had a loamy sand texture with a sand, clay and silt ranging between 77.18 and 85.18 %, 10.28 and 12.28 % and 4.54 and 10.54 %, respectively (Appendix D). The bulk density of the site was 1.35 g/cm^3, gravimetric moisture content 10.42 g/g, volumetric moisture content of 14.07 cm^3/cm^3, total porosity 49.06 %, air-filled porosity 34.99 % and an aggregate stability of 76.26 % (Table 4.1). For the hydrological and hydraulic properties, the recorded values were as follow: cumulative infiltration amount = 191.47 mm, infiltration rate = 0.05 mms^{-1}, Sorptivity = 1.15 mms$^{-1/2}$, steady state infiltrability = 0.05 mms^{-1} and a saturated hydraulic conductivity = 0.08 mms^{-1}.

4.1.3.2 Cocoa plantation

From Table 4.1, the soil texture of the cocoa plantation falls under the sandy loam textural class with a sand, clay and silt ranging between 65.18 and 79.18 %, 10.28 and 16.28 % and 10.54 and 18.54 %, respectively (Appendix D). The bulk density of the site was 1.37 g/cm^3, gravimetric moisture content 12.75 g/g, volumetric moisture content of 17.47 cm^3/cm^3, total porosity 48.30 %, air-filled porosity 30.83 % and an aggregate stability of 68.94 %. For the hydrological and hydraulic properties, the recorded values were as follows: cumulative infiltration amount = 15.59 mm, infiltration rate = 0.004 mms^{-1}, Sorptivity = 0.23 mms$^{-1/2}$, steady state infiltrability = 0.004 mms^{-1} and a saturated hydraulic conductivity of = 0.007 mms^{-1}.

4.1.3.3 Coffee plantation

The textural class of the coffee plantation belongs to the sandy loam with a sand, clay and silt ranging between 77.18 and 83.18 %, 10.28 and 14.28 % and 6.54 and 12.54 %, respectively (Appendix D). The bulk density of the site was 1.41g/cm^3, gravimetric moisture content 11.98 g/g, volumetric moisture content of 16.89

cm^3/cm^3, total porosity 46.79 %, air-filled porosity 29.91 % and an aggregate stability of 64.21 %. For the hydrological and hydraulic properties, the recorded values were as follows: cumulative infiltration amount = 150.07 mm, infiltration rate = 0.04 mms^{-1}, Sorptivity = 0.89 $mms^{-1/2}$, steady state infiltrability = 0.04 mms^{-1} and a saturated hydraulic conductivity = 0.06 mms^{-1}.

4.1.3.4 Cashew plantation

On the other hand, the cashew plantation belongs to the sandy loam textural class with a sand, clay and silt ranging between 71.18 and 79.18 %, 10.28 and 12.28 % and 10.54 and 16.54 %, respectively (Appendix D). The bulk density of the site was 1.47 g/cm^3, gravimetric moisture content of 14.45 g/g, volumetric moisture content of 21.25 cm^3/cm^3, total porosity of 44.53 %, air-filled porosity of 23.28 % and an aggregate stability of 74.58 %. For the hydrological and hydraulic properties, the recorded values were as follows: cumulative infiltration amount = 69.58 mm, infiltration rate = 0.02 mm^{s-1}, Sorptivity = 0.42 $mm^{s-1/2}$, steady state infiltrability = 0.02 mm^{s-1} and a saturated hydraulic conductivity = 0.03 mm^{s-1}.

4.1.3.5 Mango plantation

Mango plantation was of the sandy loam textural class with a sand, clay and silt ranging between 65.18 and 79.18 %, 10.28 and 11.28 % and 10.54 and 24.54 % respectively, (Appendix D). The bulk density of the site was 1.5 g/cm^3, gravimetric moisture content 11.08 g/g, volumetric moisture content of 16.61 cm^3/cm^3, total porosity of 43.39 %, air-filled porosity of 26.78 % and an aggregate stability of 55.4 %. For the hydrological and hydraulic properties, the recorded values were as follows: cumulative infiltration amount = 27.56 mm, infiltration rate = 0.008 mms^{-1}, Sorptivity

= 0.18 $mms^{-1/2}$, steady state infiltrability = 0.008 mms^{-1} and a saturated hydraulic conductivity = 0.01 mms^{-1}.

4.2 Soil physical properties

The results on the influence of land uses and seasonal variabilities on soil physical characteristics are presented in Table 4.2.

4.2.1 Bulky density (ρ_b)

The highest bulk density was recorded under the mango plantation (1.452 g/cm^3) followed by cashew (1.405 g/cm^3), coffee (1.332 g/cm^3) and cocoa plantations (1.331 g/cm^3), respectively while the forest stand (1.271 g/cm^3) had the least bulk density (Figure 4.4a). The bulk densities under mango and cashew plantations were significantly different ($p < 0.05$) from those of the coffee plantation, cocoa plantation and forest stands. However, the bulk density under mango plantation was not significantly different ($p < 0.05$) from cashew plantation. Also, there were no significant differences ($p < 0.05$) among, coffee plantation, cocoa plantation and forest stand (Table 4.2).

The highest bulk densities were recorded under MRS2016 (1.389 g/cm^3) followed by MNRS2016 (1.388 g/cm^3), MRS2017 (1.359 g/cm^3), DS2016 (1.344 g/cm^3), MNRS2017 (1.343 g/cm^3) and DS2017 (1.328 g/cm^3) respectively (Figure 4.5b). There were no significant differences ($p < 0.05$) among the six seasons. Nevertheless, it was observed that bulk density values from similar seasons in different years did reduce thus for example the dry season, major rain season and minor rain season in different years did reduce thus DS2016 > DS2017, MRS2016 > MRS2017, MNRS2016 > MNRS2017 (Table 4.2). Statistical analysis of bulk density showed that, there were no interaction between the land use and season (Table 4.2)

Table 4. 2 Characteristics of soil physical properties under different land use and seasons

	Bulk density **ρ_b (g cm^{-3})**	Gravimetric water content **θ_g (g/g)**	Volumetric water content **θ_v (cm^3/cm^3)**	Total porosity **f (%)**	Aeration Porosity **ξ_a (%)**	Void ratio **e**	Degree of saturation **θ_s (%)**	Aggregate stability **ASt (%)**
Land Use								
Forest	1.271	11.36	14.19	52.03	37.83	1.122	27.62	82.34
Cocoa	1.331	12.76	16.76	49.78	33.02	1.004	33.73	69.14
Coffee	1.332	10.39	13.95	49.7	35.76	1.019	29.44	69.56
Cashew	1.405	13.36	18.92	46.97	28.05	0.894	41.06	79.11
Mango	1.452	11.17	16.15	45.22	29.07	0.837	35.74	65.65
F pr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LSD (5%)	0.0652	1.284	1.574	2.454	2.951	0.102	3.832	3.751
Season								
DS2016	1.344	6.95	9.32	49.18	39.86	1	19.44	70.18
MRS2016	1.389	9.22	12.84	47.7	34.86	0.93	27.16	69.13
MNRS2016	1.388	15.9	21.86	47.62	25.76	0.95	47.57	73.43
DS2017	1.328	9.15	12.17	49.9	37.73	1.011	24.77	74.02
MRS2017	1.359	11.37	15.4	48.71	33.31	0.962	31.85	75.37
MNRS2017	1.343	18.25	24.37	49.33	24.95	0.999	50.33	76.82
F pr	0.434	0.001	0.001	0.472	0.001	0.649	0.001	0.002
LSD (5%)	0.0714	1.407	1.724	2.688	3.233	0.1117	4.198	4.109
Land use*Season								
F pr	0.054	0.947	0.027	0.053	0.001	0.086	0.001	1
LSD (5%)	0.1597	3.146	3.855	6.01	7.229	0.250	9.388	9.188
CV (%)	2.7	7.7	6.7	2.9	5.7	6.5	7	0.9

4.2.2. Gravimetric moisture Content (θ_g)

The highest gravimetric moisture content was recorded under cashew plantation (13.36 g/g) followed by cocoa plantation (12.76 g/g), forest stand (11.36 g/g), mango plantation (11.17 g/g) and coffee plantation (10.39 g/g). Gravimetrric moisture content under cashew and cocoa plantations were significantly different ($p < 0.05$) from forest stand, mango plantation and coffee plantation (Table 4.2). However, cashew plantation was not significantly different from cocoa plantation. There were also no significant differences among the forest, mango plantation and coffee plantation.

It was observed that, MNRS2017 (18.25 g/g) recorded the highest gravimetric moisture content followed by MNRS2016 (15.9 g/g), MRS2017 (11.37 g/g), MRS2016 (9.22 g/g) and DS2017 (9.15 g/g) while DS2016 (6.95 g/g) recorded the least gravimetric moisture content. MNRS2017, MNRS2016, MRS2017 and DS2016 were significantly different ($p < 0.05$) from all the other seasons (Table 4.2). DS2017 and MRS2016 were not significantly different ($p < 0.05$) from each other. There was a general increase in gravimetric moisture from the first season to the last season. It was observed from Table 4.2, that there was no interaction between plantations and seasons

4.2.3. Volumetric moisture Content (θ_v)

Soils under cashew plantation recorded the highest (18.92 cm^3/cm^3) volumetric moisture content value followed by cocoa plantation (16.76 cm^3/cm^3), mango plantation (16.15 cm^3/cm^3) and forest stand (14.19 cm^3/cm^3), while coffee plantation (13.95 cm^3/cm^3) recorded the least (Table 4.2).

Cashew plantation was significantly different ($p < 0.05$) from all the other treatments. Cocoa plantation and mango plantations were significantly different from forest stand and coffee plantation but were not significantly different ($p < 0.05$) from each other. It was also observed that forest stand and cashew plantation was not significantly different from each other (Table 4.2).

A similar trend was observed in season volumetric moisture content as observed in gravimetric moisture where MNRS2017 (24.37 cm^3/cm^3) recorded the highest volumetric moisture content followed by MNRS2016 (21.86 cm^3/cm^3), MRS2017 (15.4 cm^3/cm^3), MRS2016 (12.84 cm^3/cm^3) and DS2017 (12.17 cm^3/cm^3), while DS2016 (9.32 cm^3/cm^3) recorded the least.

From the analysis, MNRS2017, MNRS2016, MRS2017 and DS2016 were significantly different ($p < 0.05$) from all the other seasons. While DS2017 and MRS2016 were not significantly different ($p < 0.05$) from each other. There was a general increase in volumetric moisture from the first season to the last season.

It was observed that similar seasons did record similar range of values, that is, you have the results of the minor rain seasons (MNRS2016 and MNRS2017) following each other closely followed by the major rain seasons (MRS2017 and MRS2016) and the dry seasons (DS2017 and DS2016).

An interaction was observed between land use and season when the data was analysed (Table 4.2). It was observed that cashew×MNRS2017 recorded the highest volumetric moisture (29.57 cm^3/ cm^3) followed by cashew×MNRS2016 (26.89 cm^3/ cm^3) while coffee×DS2016(6.91 cm^3/ cm^3) followed by forest×DS2016 (8.01 cm^3/ cm^3) (Figure 4.3). The anaylsis revealed that coffee×DS2016, forest×DS2016, mango×DS2016, cocoa×DS2016 and cashew×DS2016 were significantly different ($p < 0.05$) from coffee×MNRS2017, forest×MNRS2017, mango×MNRS2017, cocoa×MNRS2017 and cashew×MNRS2017.

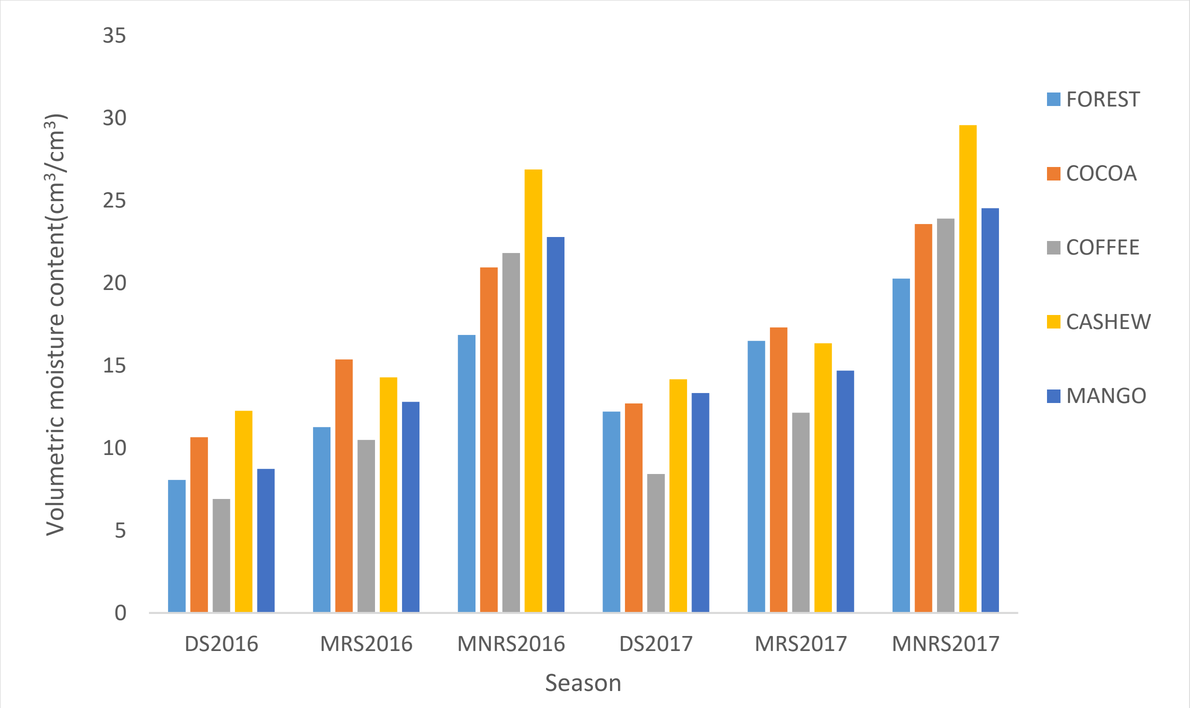

Figure 4.3 Land use Interaction effects on volumetric moisture content

4.2.4. Total porosity (*f*)

The highest total soil porosity was recorded under Forest stand (52.03 %) followed by cocoa plantation (49.78 %), coffee plantation (49.7 %) and cashew plantations (46.97 %) while mango plantation (45.22%) recorded the least (Figure 4.4c). It was observed that forest stand, cocoa plantation and coffee plantation were not significantly different ($p < 0.05$) from each other but were all significantly different ($p < 0.05$) from cashew plantation and mango plantation. In turn, cashew plantation was not significantly different from mango plantation (Table 4.2).

There was no significant difference ($p < 0.05$) among any of the seasons however all the 2017 dry, major rain and minor rain seasons recorded higher values than 2016 dry, major rain and minor rain seasons, respectively (Figure 4.4d).

There was no interaction between the land use and seasonal values of total porosity recorded (Table 4.2).

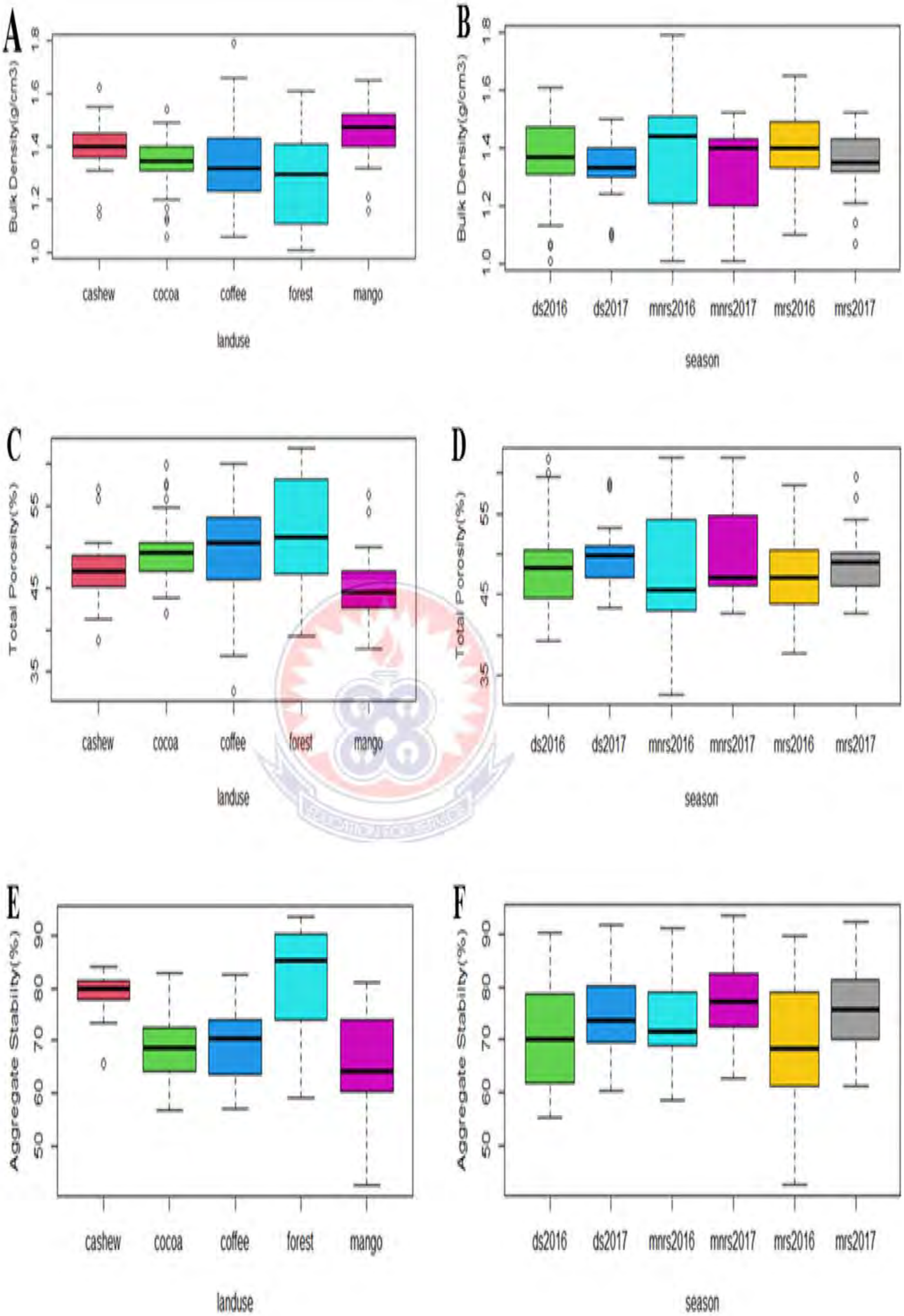

Figure 4. 4 Land use and seasonal box plot representation of bulk density, total porosity and aggregate stability

4.2.5. Air-filled porosity (ξ_a)

The highest air-filled porosity was recorded under Forest stand (37.83 %) followed by coffee plantation (35.76 %), cocoa plantation (33.02 %) and mango plantations (29.07 %) with cashew plantation (28.05 %) recording the least.

Air-filled porosities under Forest stand and coffee plantations were not significantly different ($p < 0.05$) from each other, but forest stand was significantly different ($p < 0.05$) from all the other plantations. Coffee plantation was not significantly different ($p < 0.05$) from cocoa plantation, but was significantly different ($p < 0.05$) from mango plantation and cashew plantation. Also, mango plantation and cashew plantation were not significantly different from each other.

Analysis of seasonal air-filled porosity revealed that DS2016 (39.86 %) had the highest air-filled followed by DS2017 (37.73 %), MRS2016 (34.86 %), MRS2017 (33.31 %) and MNRS2016 (25.76 %) while MNRS2017 (24.95 %) recorded the least air-filled value (Table 4.2).

It was observed that, DS2016 and DS2017 were not significantly different ($p < 0.05$) from each other. DS2016 was significantly different ($p < 0.05$) from all the other seasons while DS2017 was not significantly different ($p < 0.05$) from MRS2016, however, it was significantly different from seasons MRS2017, MNRS2016 and MNRS2017. It was also observed that season MNRS2016 and MNRS2017 were not significantly different from each other but different from all the other seasons (Table 4.2). Similar seasons closely followed each other. That is, the results of the minor rain seasons (MNRS2017 and MNRS2016) following each other closely followed by the major rain seasons (MRS2017 and MRS2016) and the dry seasons (DS2017 and DS2016).

An interaction between the land use and seasons was observed (Table 4.2). Significant differences ($p < 0.05$) were observed among the different factor combinatins of land use×season of air-filled porosity (Table 4.2).

Table 4.3 Land use and season interaction on air-filled porosity

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	45.96	38.4	46.56	33.55	34.81
MRS2016	38.39	31.19	39.14	35.38	30.21
MNRS2016	36.4	30.66	21.77	16.2	23.76
DS2017	40.62	37.34	44.78	33.07	32.86
MRS2017	32.48	31.22	38.5	34.37	29.99
MNRS2017	33.16	29.33	23.79	15.71	22.78
LSD (0.05)			3.855		
CV (%)			6.7		

Coffee×DS2016 recorded highest (46.56 %) air-filled porosity followed by forest×DS2016 (45.96 %), while cashew×MNRS2017 (15.71 %) recorded the least value followed by cashew×2016 (16.2 %).

4.2.6. Void ratio (*e*)

It was observed that forest stand (1.122) recorded the highest void ratio value among the plantations followed by coffee plantation (1.019), cocoa plantation (1.004) and cashew plantation (0.894) while mango plantation (0.837) recorded the least void ratio. Forest stand was not significantly different ($p < 0.05$) from coffee plantation but was significantly different ($p < 0.05$) from cocoa plantation, cashew plantation and mango plantation. It was also observed that cashew plantation and mango plantation were not significantly different ($p < 0.05$) from each other but were both significantly different ($p < 0.05$) from cocoa plantation (Table 4.2).

From cursory the highest void ratio was recorded under DS2017 followed by DS2016, MNRS2017, MRS2017 and MNRS2016 while MRS2016 recorded the least.

There were no significant differences ($p < 0.05$) among the seasons and no interaction between the land use and seasonal values of void ratio was observed (Table 4.2).

4.2.7. Degree of saturation (θ_s)

The highest degree of saturation was recorded under Cashew plantation (41.06 %) followed by mango plantation (35.74 %), cocoa plantation (33.73 %) and coffee plantation (29.44 %) while forest stand (27.62 %) recorded the least Degree of Saturation value.

Cashew plantation was significantly differently ($p < 0.05$) from all the other plantations. The degree of saturation under mango plantation was significantly differently ($p < 0.05$) from coffee plantation and forest stand but not significantly differently ($p < 0.05$) from cocoa plantation. Also, coffee plantation was not significantly differently ($p < 0.05$) from forest stand (Table 4.2). MNRS2017 (50.33 %) recorded the highest degree of saturation value followed by MNRS2016 (47.57 %), MRS2017 (31.85 %), MRS2016 (27.16 %) and DS2017 (24.77 %) while DS2016 (19.44 %) recorded the least degree of saturation value. MNRS2017 and DS2016 were significantly differently ($p < 0.05$) from all the other seasons. However, MNRS2017 and MNRS2016 were not significantly differently ($p < 0.05$) from each other (Table 4.2). Also, DS2017 and MRS2016 were not significantly differently ($p < 0.05$) from each other. A trend was observed that with the exception of MNRS2017 and MNRS2016 similar seasons closely followed each other and were significantly different ($p < 0.05$) from each other (Table 4.2).

Interaction between land uses and season was significant for degree of saturation when the data was analysed. There were significant differences ($p < 0.05$) among the different factor combinations, with cashew×MNRS2017 recoding the highest (65.42 %) degree of saturation followed by cashew×MNRS2016 (62.52 %) while coffee×DS2016 (13.05 %) recorded the least value followed by forest×DS2016 (15.36 %).

Table 4.3 Land use and season nteraction on degree of saturation

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	15.36	21.67	13.05	26.89	20.22
MRS2016	22.77	33	21.45	28.94	29.65
MNRS2016	31.78	41.47	51.82	62.52	50.27
DS2017	23.62	25.39	15.75	30.06	29.02
MRS2017	33.8	35.63	24.32	32.53	32.95
MNRS2017	38.39	45.21	50.26	65.42	52.35
LSD (5%)			9.388		
CV (%)			7		

While forest×DS2016, cocoa×DS2016, coffee×DS2016, cashew×DS2016 and mango×DS2016 were not significantly different from each other, they were all significantly different from forest×MNRS2017, cocoa×MNRS2017, coffee×MNRS2017, cashew×MNRS2017 and mango×MNRS2017(Table 4.3).

4.2.8. Aggregate Stability (*ASt*)

The highest aggregate stability was recorded under forest stand (82.34 %) followed by cashew plantation (79.11 %), coffee (69.56 %) and cocoa plantations (69.14 %) while mango plantation (65.65 %) recorded the least aggregate stability value (Figure 4.5e). Mango plantation was not significantly different ($p < 0.05$) from cocoa plantation but was significantly different ($p < 0.05$) from all the other land use. Similarly, forest stand and cashew plantation were not significantly different ($p < 0.05$) from each other but were significantly different from all other land use (Table 4.3).

It was observed that, the highest aggregate stability was recorded under MNRS2017 (76.82 %) followed by MRS2017 (75.37 %), DS2017 (74.02 %), MNRS2016 (73.43 %) and DS2016 (70.08 %) while MRS2016 (69.13 %) recorded the least aggregate stability value. MRS2016 was not significantly different ($p < 0.05$) from DS2016 but was significantly different ($p < 0.05$) from all other seasons. MNRS2016, DS2017, MRS2017 and MNRS2017were not significantly different ($p < 0.05$) from each other. But for MRS2016, there was a steady increase from the first season to the last season where DS2016 < MNRS2016 < DS2017 < MRS2017 < MNRS2017 (Figure 4.5f). There were no interactions between the land use and seasonal aggregate stability values (Table 4.2).

4.3 Results of soil hydraulic and hydrological properties

The effects of land use and seasonal variabilities on soil hydraulic and hydrological properties are presented in Table 4.3.

4.3.1 Cumulative Infiltration amount (I)

At the hour mark, cumulative infiltration amount was highest under forest stands (216.9 mm) followed by coffee plantation (138 mm), cocoa plantation (92.6 mm), cashew plantation (79.1 mm) and mango plantation (35.1 mm), respectively as presented in Table 4.3. Figure 4.8a - e shows trends of cumulative water entry into the soil with time over the different seasons.

A similar trend was observed in the seasons where there was steady significant difference among the seasons. However, unlike the vegetation stands, significant differences were observed from 60 s to the 2400 s (thus the fortieth minutes) but not by the hour mark (3600 s) (Appendix C).

It can be observed that, MNRS2017 (154.1 mm) recorded the highest cumulative infiltration amount followed by MRS2017 (116 mm), DS2017 (114.3 mm), MRS2016

(104.1 mm) and DS2016 (95.2 mm) while MNRS2016 (90.2 mm) recorded the least value of cumulative infiltration amount. But for MNRS2016 there was a steady improvement in the cumulative infiltration rate from DS2016 to MNRS2017.

There was no interaction between land use and seasonal variations in cumulative infiltration amount values

Table 4. 4 Land use and seasonal variabilities influence on soil hydraulic and hydrological properties

	Infiltration amount **I (mm)**	Infiltration rate i *(mms^{-1})*	Sorptivity **S** *(mm s$^{-1/2}$)*	Steady state infiltrability **K_o** *(mm s^{-1})*	*Saturated hydraulic conductivity* **K_s** *(mm s^{-1})*
Land Use					
Forest	216.9	0.060	1.456	0.061	0.106
Cocoa	92.6	0.026	0.929	0.026	0.045
Coffee	138.0	0.038	1.016	0.039	0.063
Cashew	79.1	0.022	0.574	0.022	0.041
Mango	35.1	0.010	0.391	0.010	0.022
F pr	0.001	0.001	0.001	0.001	0.001
LSD (5%)	40.71	0.011	0.388	0.012	0.019
Season					
DS2016	95.20	0.0265	0.643	0.0269	0.036
MRS2016	104.1	0.0289	0.674	0.0294	0.043
MNRS2016	90.20	0.0251	0.550	0.0254	0.047
DS2017	114.3	0.0317	0.958	0.0325	0.058
MRS2017	116.1	0.0323	1.013	0.0331	0.071
MNRS2017	154.1	0.0428	1.401	0.0438	0.077
F pr	0.076	0.076	0.001	0.064	0.001
LSD (5%)	44.59	0.012	0.425	0.013	0.021
Land use *Season					
F pr	0.983	0.983	0.326	0.981	0.051
LSD (5%)	99.72	0.028	0.951	0.028	0.047
CV (%)	21.8	21.8	18.1	21.7	20.4

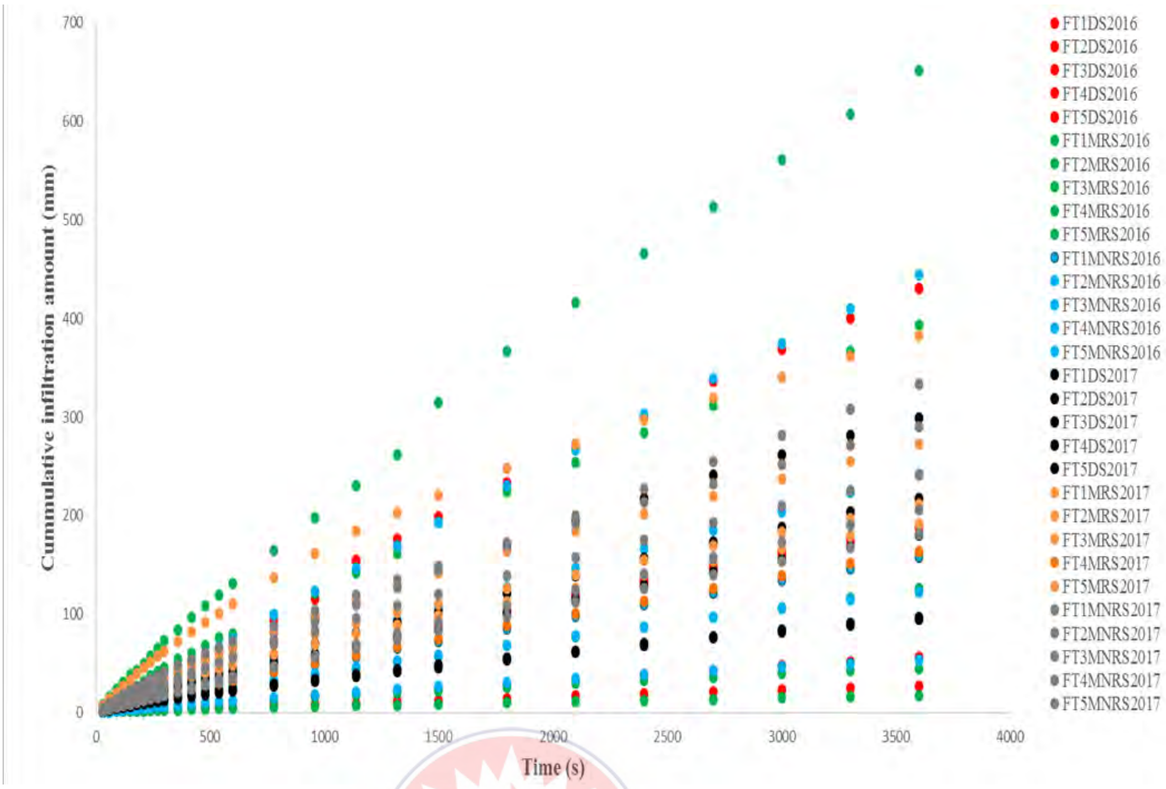

Figure 4. 5 Cumulative infiltration amount graph of soils under forest stand

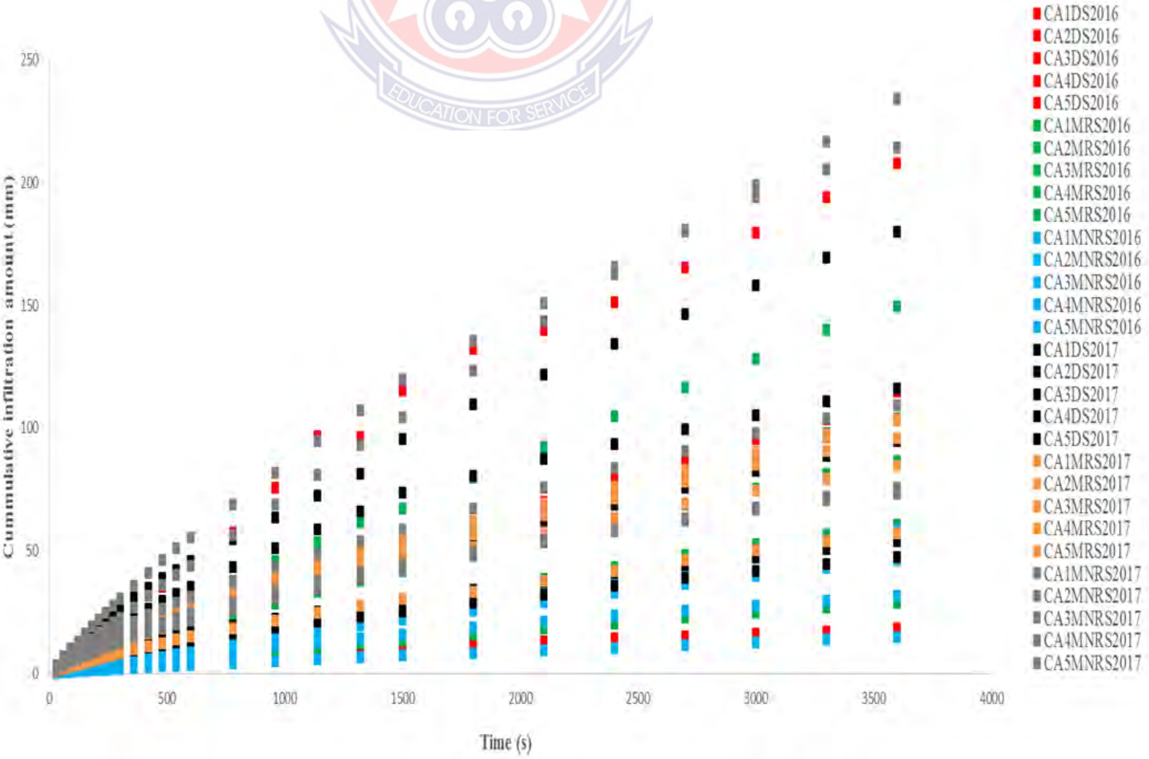

Figure 4. 6 Cumulative infiltration amount graph of soils under cocoa plantations

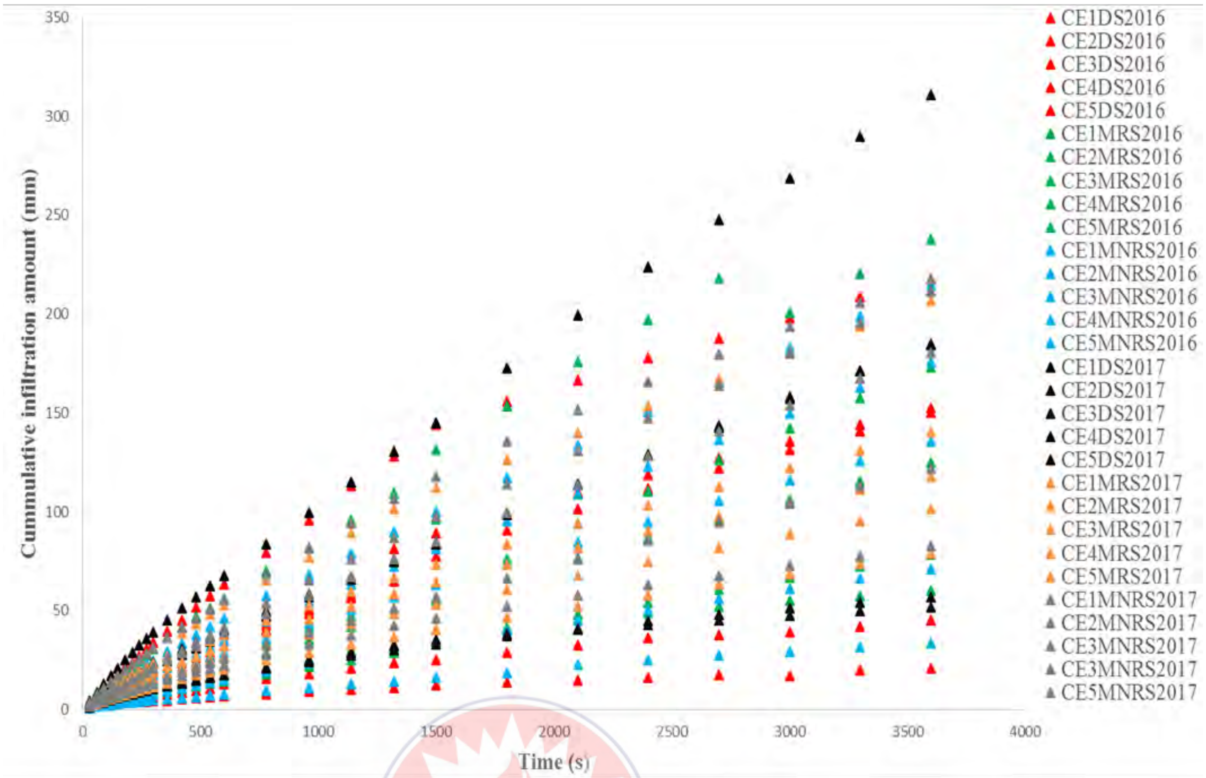

Figure 4. 7 Cumulative infiltration amount graph of soils under coffee

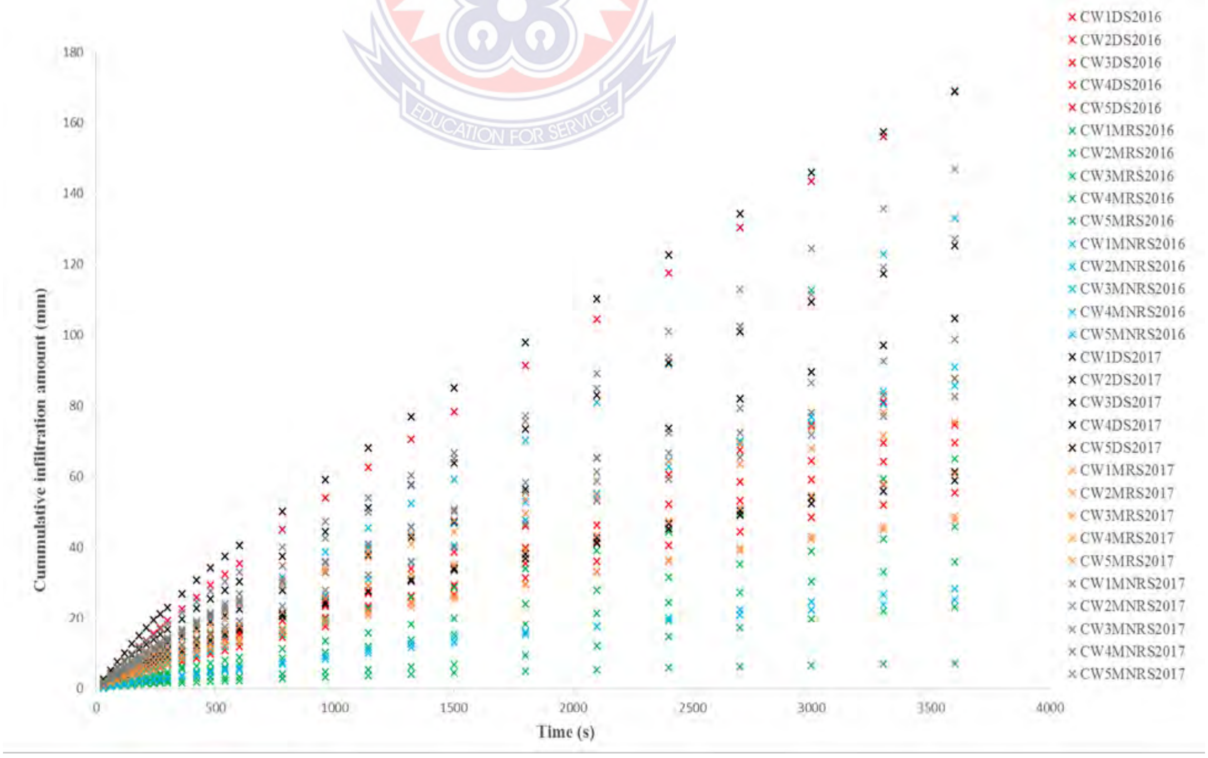

Figure 4. 8 cumulative infiltration amount graph of soils under cashew plantations

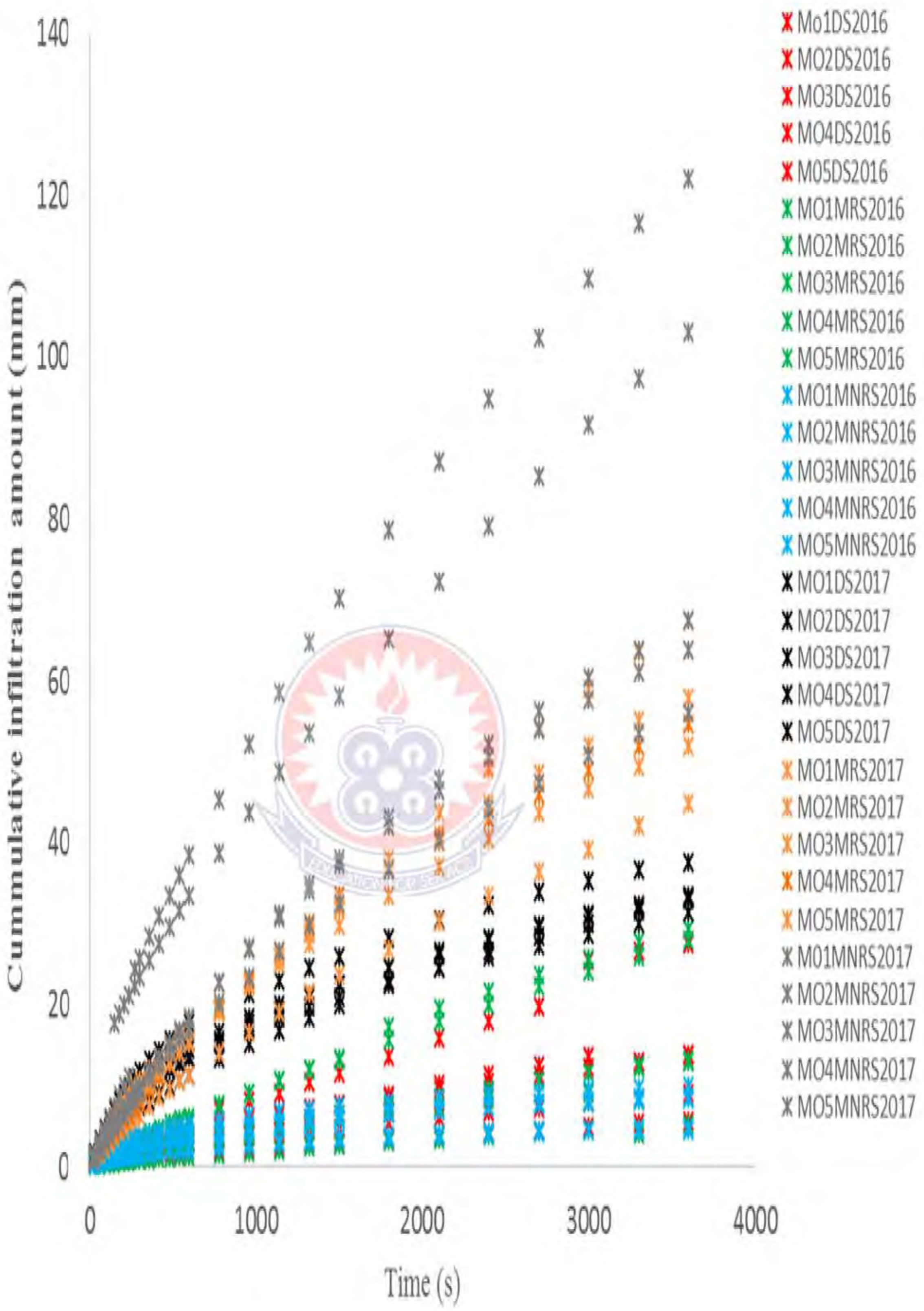

Figure 4. 9 Cumulative infiltration amount graph of soils under mango plantations

4.3.2. Infiltration rate (i)

Similar to cumulative infiltration amount, there were a steady significant ($p < 0.05$) difference among the infiltration rates of the different land uses from the first 30 s to the 3600 s (hour mark) (Table 4.4). Figure 4.10 presents the graphical representation of infiltration rate recorded in the various seasons under each of the vegetation stand. At the hour mark, the highest infiltration rate was recorded under forest stand (0.0603 mm/s) followed by coffee plantation (0.0383 mm/s), cocoa plantation (0.0257 mm/s), cashew plantation (0.0220 mm/s) and mango plantation (0.0098 mm/s), respectively (Figure 4.10a-e). By the hour mark, all the land uses were significantly different ($p < 0.05$) from each other (Table 4.4).

A similar trend was observed in the seasons where there was a steady significant difference among the seasons. However, unlike the vegetation stands, the significant difference was from 60 s to the 2400 s (thus the fortieth minute) but not by the hour mark (3600 s) (Appendix B). MNRS2017 (0.0428 mm/s) recorded the highest infiltration rate followed by MRS2017 (0.0323 mm/s), DS2017 (0.0317 mm/s), MRS2016 (0.0289 mm/s) and DS2016 (0.0265 mm/s) while MNRS2016 (0.0251 mm/s) recorded the least value of infiltration rate (Figure 4.10a-e). With the exception of MNRS2016, there was a steady improvement in the infiltration rate from DS2016 to MNRS2017 (Table 4.4).

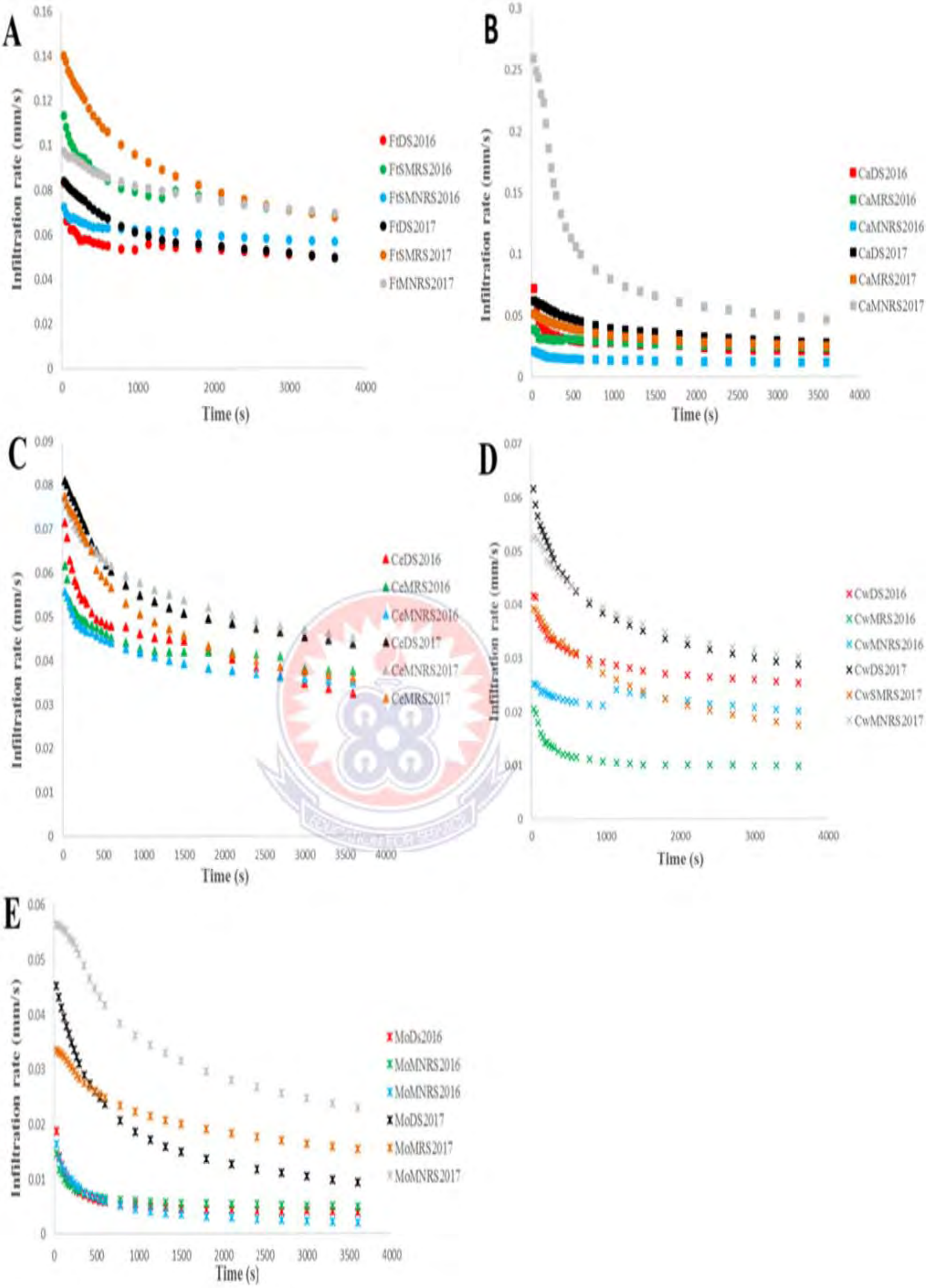

Figure 4. 10 Infiltration rate graph of soils under forest stand, cocoa, coffee, cashew and mango plantations

Infiltration rate of A=Forest, B=Cocoa, C=Coffee, D=Cashew and E=Mango

4.3.3 Sorptivity (S)

The least sorptivity value was recorded under mango plantation (0.391 mm/s$^{1/2}$) while the forest stand (1.456 mm/s$^{1/2}$) recorded the highest sorptivity value (Figure 4.11a-e). The forest, cocoa plantation (0.929 mm/s$^{1/2}$) and coffee plantation (1.016 mm/s$^{1/2}$) were significantly ($p < 0.05$) different from both cashew plantation (0.574 mm/s$^{1/2}$) and mango plantation (Table 4.4).

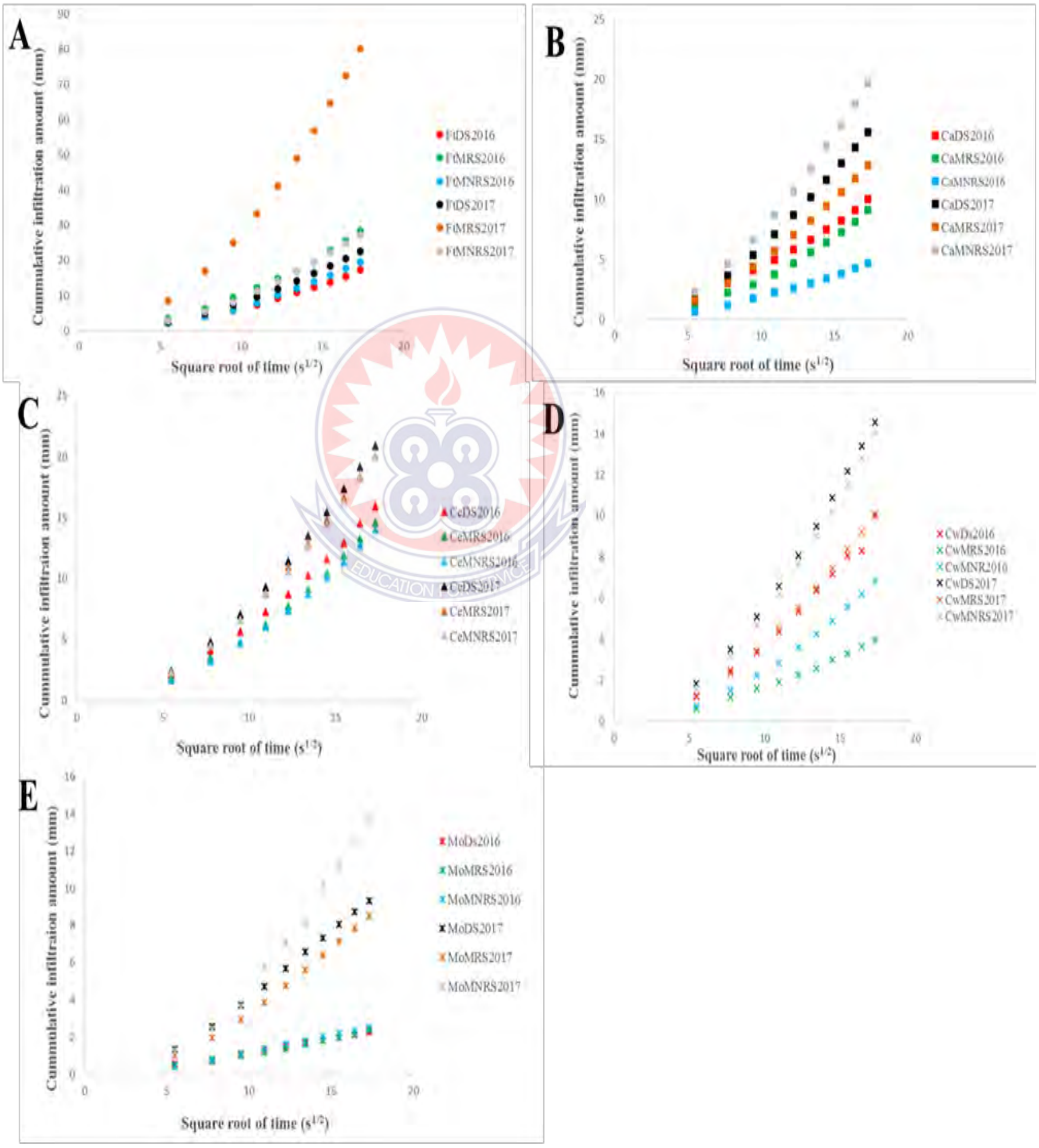

Figure 4. 11 Sorptivity graph of soils under forest stand, cocoa, coffee, cashew and mango plantations

Sorptivity graph of A=Forest, B=Cocoa, C=Coffee, D=Cashew and E=Mango

Whereas cashew plantation and mango plantations were not significantly ($p < 0.05$) different from each other, there were significant differences among forest stand, cocoa plantation and coffee plantations (Table 4.4).

The highest sorptivity was recorded under MNRS2017 (1.401 mm/s$^{1/2}$) followed by MRS2017 (1.013 mm/s$^{1/2}$), DS2017 (0.958 mm/s$^{1/2}$), MRS2016 (0.674 mm/s$^{1/2}$), DS2016 (0.643 mm/s$^{1/2}$) while MNRS2016 (0.550 mm/s$^{1/2}$) (Figure 4.11a-e). Apart from MRS2017, MNRS2017 was significantly different from all the other seasons. There were no significant differences ($p < 0.05$) among the seasons (DS2016, MRS2016 and MNRS2016) just as there was no significant difference ($p < 0.05$) between DS2017 and MRS2017. Apart from MNRS2016, there was a steady improvement in the sorptivity of the succeeding seasons (Table 4.4). There was no interaction between the land use and the seasonal values of sorptivity.

4.3.4 Steady state infiltrability (K_0)

The highest steady state infiltrability was recorded under forest stand (0.0612 mm/s) followed by coffee plantation (0.039 mm/s), cocoa plantation (0.0264 mm/s) and cashew plantations (0.0224 mm/s) while mango plantation (0.0101 mm/s) recorded the least steady state infiltrability. Forest and coffee plantation were significantly different ($p < 0.05$) from all the other treatments. Cocoa plantation was significantly different ($p < 0.05$) from cashew plantation and mango plantationwhich had similar steady state infiltrabity, (Table 4.4).

It was observed that, MNRS2017 (0.0438 mm/s) recorded the highest steady state infiltrability followed by MRS2017 (0.0331 mm/s), DS2017 (0.0325 mm/s) MRS2016 (0.0294 mm/s) and DS2016 (0.0269 mm/s) whereas MNRS2016 (0.0254 mm/s) recorded the least steady state infiltrability.

There were no significant differences among the seasons, neither was there a significant difference between land use × seasonal intraction steady state infiltrability values (Table 4.4).

4.3.5 Hydraulic conductivity (K_s)

The least saturated hydraulic conductivity was recorded under mango plantation (0.02146 mm/s) recorded followed by cashew plantation (0.0411 mm/s), cocoa plantation (0.04521 mm/s) and coffee plantation (0.06282 mm/s), while forest (0.10626 mm/s) recorded the highest hydraulic conductivity value. Forest was significantly different ($p < 0.05$) from all other land use. Coffee plantation was not significantly different ($p < 0.05$) from cocoa plantation and cashew plantation but was significantly different ($p < 0.05$) from mango plantation which was not significantly different ($p < 0.05$) from cashew plantation and cocoa plantation (Table 4.4).

The least hydraulic conductivity was recorded under DS2016 (0.03605mm/s), while MNRS2017 (0.07735 mm/s) recorded the highest value followed by MRS2017 (0.0709 mm/s), DS2017 (0.05778 mm/s), MNRS2016 (0.04682 mm/s), MRS2016 (0.04332 mm/s) (Table 4.3). MNRS2017 was not significantly different ($p < 0.05$) from MRS2017, DS2017 and MNRS2016, but significantly different ($p < 0.05$) from MRS2016 and DS2016. DS2016 was not significantly different ($p < 0.05$) from MRS2016, MNRS2016 and DS2017 although it was significantly different ($p < 0.05$) from MRS2017.

There was no interaction between the land use and seasonal hydraulic conductivity values (Table 4.4).

4.4 Litter fall and carbon accumulation

Land use and seasonal effects on litter fall and on the levels of soil organic carbon, carbon stock and carbon sequestration are presented in Table 4.5.

4.4.1 Litter fall

The highest amount litter fall was recorded under the forest stand (3.277 t/ha) followed by cashew plantation (3.135 t/ha), cocoa plantation (3.091 t/ha), coffee plantation (2.868 t/ha) and mango plantations (2.27 t/ha), respectively (Figure 4.15a). All the other treatments were significantly different ($p < 0.05$) from mango plantation. Forest was also significantly different ($p < 0.05$) from coffee plantation (Table 4.5). However, there were no significant differences ($p < 0.05$) among the forest stand, cashew plantation and cocoa plantations. There was also no significant difference ($p < 0.05$) among cashew plantation, cocoa plantation and coffee plantation (Table 4.4). It was observed that the highest litter fall was recorded under DS2017 (4.062 t/ha) followed by DS2016 (3.647 t/ha), MNRS2017 (3.197 t/ha), MNRS2016 (2.854 t/ha) and MRS2017 (2.012 t/ha), while MRS2016 (1.798 t/ha) recorded the lowest litter fall value (Figure 4.15b). Litter fall between DS2017 and DS2016 were not significantly different ($P < 0.05$) from each other, but both were significantly different ($P < 0.05$) from those recorded under MRS2016, MNRS2016, MRS2017 and MNRS2017. MNRS2016 and MNRS2017 were not significantly different ($P < 0.05$), but were both significantly different ($P < 0.05$) from MRS2016 and MRS2017. It was observed that similar seasons were not significantly different ($P < 0.05$) from each other (Table 4.4). There was an interaction between land use and season on litter fall values. Forest×DS2017 recorded the highest (4.925 t/ha) litter fall followed by Cashew ×MNRS2017 (4.139 t/ha) and coffee×DS2017(4.133 t/ha) while coffee×MRS2016 recorded the least (1.266 t/ha) value followed by mango×MNRS2016 (1.305 t/ha) and. cashew×MRS2016 (1.35 t/ha).

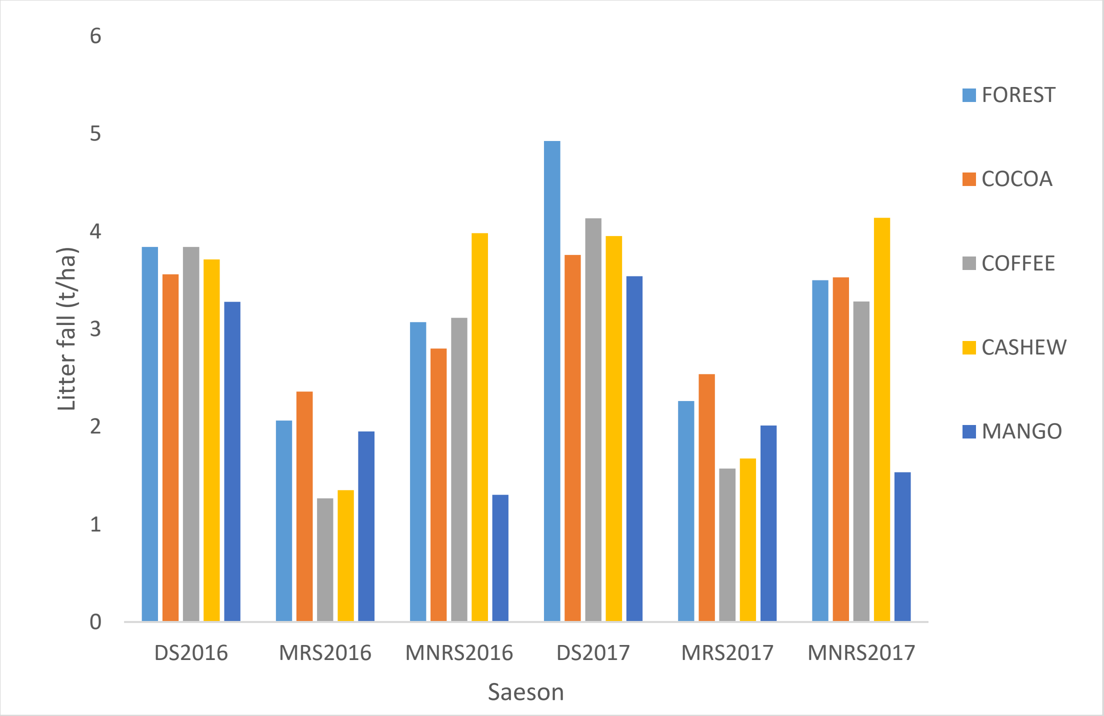

Figure 4.12 Land use and season interaction on litter fall

Except for, mango×DS2016 and mango×MNRS2017, fores×DS2016, cocoa×DS2016, coffee×DS2016 and cashew×DS2016 were not significantly different ($P < 0.05$) from forest×MNRS2017, cocoa×MNRS2017, coffee×MNRS2017 and cashew×MNRS2017 (Figure 4.12).

Table 4. 5 Land use and seasonal effect on litter fall and carbon accumulation

	Litter Fall (t/ha)	**Soil organic Carbon soc (%)**	**Carbon stocks C Stk (Mg C/ha)**	**Carbon Sequestration C Sqt (CO_2 Mg /ha)**
Land use				
Forest	3.277	2.392	45.7	167.7
Cocoa	3.091	2.356	47.02	172.6
Coffee	2.868	2.343	46.86	172
Cashew	3.135	2.232	47.05	172.7
Mango	2.27	2.244	48.82	179.2
Fpr	0.001	0.001	0.153	0.153
LSD (5%)	0.346	0.028	2.39	8.77
Season				
DS2016	3.647	2.2336	44.96	165
MRS2016	1.798	2.274	47.34	173.7
MNRS2016	2.854	2.312	48.11	176.6
DS2017	4.062	2.309	45.92	168.5
MRS2017	2.012	2.362	48.15	176.7
MNRS2017	3.197	2.389	48.04	176.3
Fpr	0.001	0.001	0.074	0.074
LSD (5%)	0.379	0.031	2.618	9.61
Land*Season				
Fpr	0.001	0.463	0.049	0.049
LSD (5%)	0.847	0.070	5.854	21.48
CV (%)	4.5	0.9	3.2	3.2

4.4.2 Soil organic carbon

The highest soil organic carbon content was recorded under Forest stand (2.392 %) followed by cocoa plantation (2.356 %), coffee plantation (2.343 %) and mango plantations (2.244 %), while cashew plantation (2.232 %) recorded the least (Figure 4.13c).

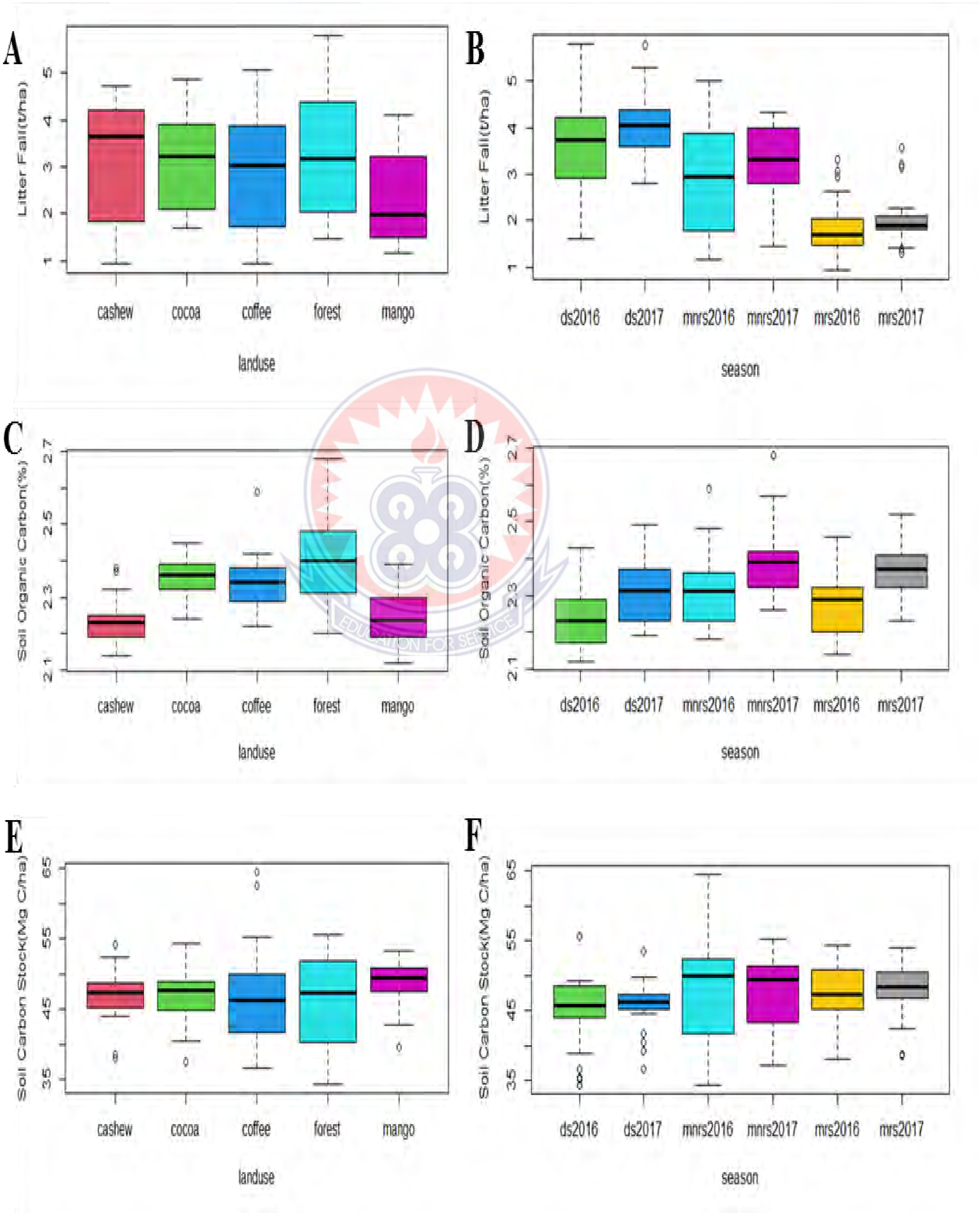

Figure 4. 13 Box plot of land use and seasonal effect on litterfall, soil organic carbon and soil carbon stocks

The forest stand was significantly different ($P < 0.05$) from all the other treatments. Soil organic carbon under cocoa plantation and coffee plantation were significantly different ($P < 0.05$) fromthat of mango plantation and cashew plantation, which were similar ($P < 0.05$). It was observed that there was no significant difference in soil organic carbon ($P < 0.05$) between mango plantation and cashew plantation (Table 4.5).

The least soil organic carbon content was recorded under DS2016 (2.234 %) while MNRS2017 (2.3892 %) recorded the highest soil organic carbon content followed by MRS2017 (2.3624 %), MNRS2016 (2.312 %), DS2017 (2.3092 %) and MRS2016 (2.274 %) (Figure 4.15d). MNRS2017 and MRS2017 were significantly different ($P < 0.05$) from all the other seasons but were not significantly different ($P < 0.05$) from each other. Similarly, DS2017 and MNRS2016 were significantly different ($P < 0.05$) from all the other treatments but were not significantly different from each other. However, DS2016 and MRS2016 were significantly different ($P < 0.05$) from each other and also significantly different ($P < 0.05$) from all other seasons. There was no interaction between the land use and season on soil organic carbon content.

4.4.3 Soil carbon stocks

There was no significant difference ($P < 0.05$) among the different land uses (Table.4.5). However, the highest soil carbon stocks were recorded under Mango plantation (48.82 Mg C/ha) followed by cashew plantation (47.05 Mg C/ha), cocoa plantation (47.02 Mg C/ha), coffee plantation (46.86 Mg C/ha) plantations and the forest stand (45.7 Mg C/ha).

The highest soil carbon stocks were recorded under MRS2017 (48.15 Mg C/ha) and DS2016 (44.96 Mg C/ha) had the least soil carbon stocks (Figure 4.15f). There were no significant differences ($P < 0.05$) among the seasons.

There was an interaction between land use and season on soil carbon stocks values (Table 4.5). It was observed that there was significant difference ($p < 0.05$) among the factor combinations with coffee×MNRS2016 (53.79 Mg C/ha) recording the highest soil carbon stocks followed by mango×MRS2017 (50.5 Mg C/ha) while coffee×DS2016(41.46 Mg C/ha) recorded the least value followed by forest×DS20016 (41.88 Mg C/ha).

Table 4.6 Land use and season interaction on soil carbon stock

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	41.88	46.3	41.46	46.65	48.52
MRS2016	47.57	49.37	46.25	43.86	49.64
MNRS2016	43.88	45.35	53.79	50.05	47.5
DS2017	44.54	47.11	43.28	46.8	47.89
MRS2017	49.76	48.72	46.79	45.01	50.5
MNRS2017	46.57	45.26	49.61	49.93	48.84
LSD 5%			5.854		
CV (%)			3.2		

Except, coffee×MNRS2016, that assignificantly different from coffee×DS2016 and forest×DS20016 soil carbon stocks, there no significant difference among any of the treatment combinations (Table 4.6).

4.4.4 Soil carbon Sequestration

The highest soil carbon sequestration was recorded under Mango plantation (179.2 CO_2 Mg /ha), followed by cashew plantation (172.7 CO_2 Mg /ha), cocoa plantation (172.6 CO_2 Mg /ha), coffee plantation (172 CO_2 Mg /ha) plantations and the forest stand (167.7 CO_2 Mg /ha). There was no significant difference ($P < 0.05$) among the land uses (Table 4.5).

It was observed that MRS2017 (176.7 CO_2 Mg /ha) had the highest soil carbon sequestration value and DS2016 (165 CO_2 Mg /ha) recorded the least. There was no significant difference ($P < 0.05$) among the seasons.

There was an interaction between the land use and season on soil carbon sequestration values (Table 4.5). It was observed that there was significant difference ($p < 0.05$) among the factor combinations with coffee×MNRS2016 (197.4 CO_2 Mg /ha) recording the highest soil sequestration followed by mango×MRS2017 (185.3 CO_2 Mg /ha) while coffee×DS2016 (152.2 CO_2 Mg /ha) recorded the least value followed by forest×DS20016 (153.7 CO_2 Mg /ha) (Figure 4.14).

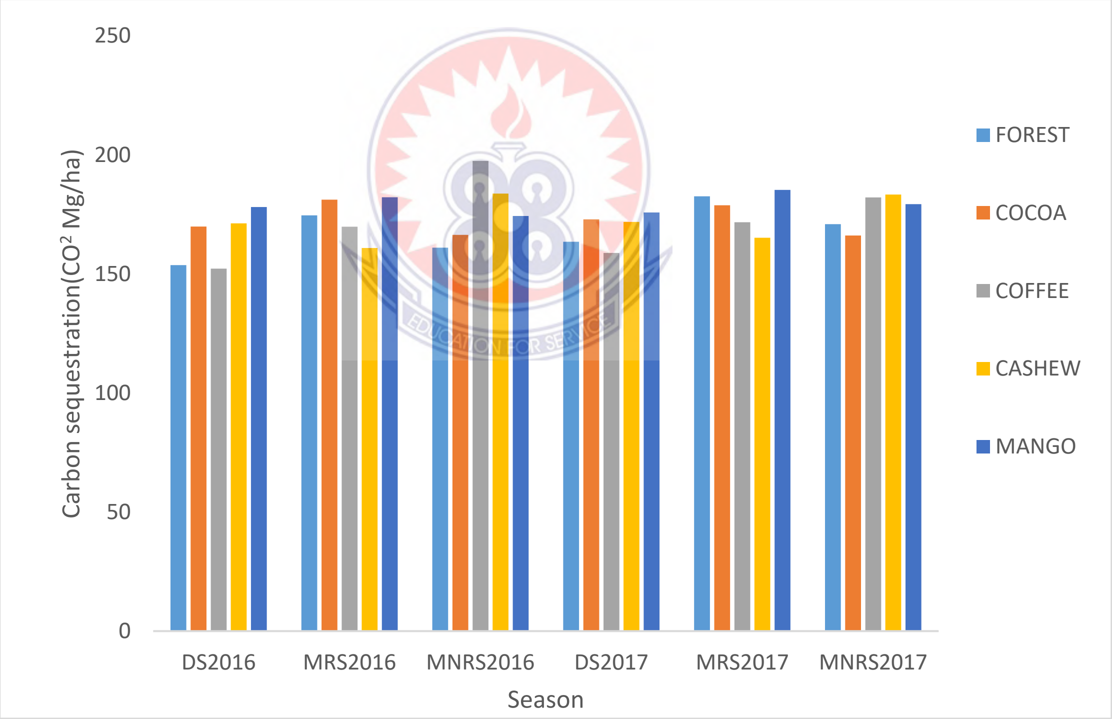

Figure 4.14 Land use and season interaction on soil carbon sequestrstion

Except, coffee×MNRS2016, that assignificantly different from coffee×DS2016 and forest×DS20016 in soilcarbon sequestration, there no significant difference among any of the treatment combinations.

4.5 Soil microbial biomass

The dynamics of soil microbial biomass under different land uses and seasons is presented in Table 4.7.

4.5.1 Microbial biomass carbon

The highest microbial biomass carbon (C_{mic}) value was recorded under Mango plantation (323.8 mg/kg) while cashew plantation (151.3 mg/kg) recorded the least (Figure 4.16a). The values for forest stand and cashew plantation were not significantly different ($p < 0.05$) each other but were significantly lower ($p < 0.05$) than all the values from the other land uses (Table 4.7)

It was observed that, the least microbial biomass carbon value was recorded under DS2016 (145.4 mg/kg) followed by DS2017 (159.1 mg/kg), MRS2016 (223.7 mg/kg), MNRS2016 (239.8 mg/kg) and MRS2017 (244.1 mg/kg), while MNRS2017 (260.4 mg/kg) recorded the highest microbial biomass carbon (Figure 4.15b).

Apart from MNRS2016 and MRS2017 that were similar ($p < 0.05$) the other seasons had microbial biomass carbon that differed significantly from each other.

Table 4. 7 Land use and seasonal effect on soil microbial biomass C, N, P

	Microbial biomass carbon Cmic**(mg/kg)**	Microbial biomass nitrogen Nmic **(mg/kg)**	Microbial biomass phosphorus Pmic **(mg/kg)**
Land use			
Forest	153.40	24.79	7.89
Cocoa	184.30	24.44	11.85
Coffee	247.50	35.63	21.75
Cashew	151.30	22.28	8.18
Mango	323.80	47.32	25.50
F pr	0.001	0.001	0.001
LSD 5%	10.15	1.701	0.811
Season			
DS2016	145.40	16.73	16.20
MRS2016	223.70	31.23	12.97
MNRS2016	239.80	36.91	13.02
DS2017	159.10	20.04	18.45
MRS2017	244.10	35.97	14.75
MNRS2017	260.40	44.46	14.81
F pr	0.001	0.001	0.001
LSD 5%	11.12	1.863	0.888
Land use × Season			
F pr	0.001	0.001	0.001
LSD 5%	24.85	4.166	1.987
CV	2.6	2.4	2.8

An interaction between land use and season on soil microbial biomass carbon was observed. Mnago×MRS2017(371.6 mg/kg) recorded the highest soil microbial biomass carbon followed by Mnago×MNRS2017(371.4) while cashew×DS2016 (94.2 mg/kg) recorded the least value, followed by forest×DS2016 (95.2 mg/kg)(Table 4.8).

Table 4. 8 Interaction of land use and season on soil microbial biomass carbon

	Season					
Land use	DS2016	MRS2016	MNRS2016	DS2017	MRS2017	MNRS2017
FOREST	95.2	162.4	173	108.4	186.8	194.6
COCOA	138	166.8	195.6	162.6	214	228.6
COFFEE	157.2	271.2	282.8	172.6	274	327.4
CASHEW	94.2	170.8	175.4	113.4	174	180.2
MANGO	242.2	347.2	372	238.6	371.6	371.4
LSD 5%	24.85					
CV (%)	2.6					

It was observed mango combinations recorded the highest value of soil microbial biomass carbon in all the different levels of season (Table 4.8). Significant differences ($p < 0.05$) were observed among the different factor combinations of land sue and season.

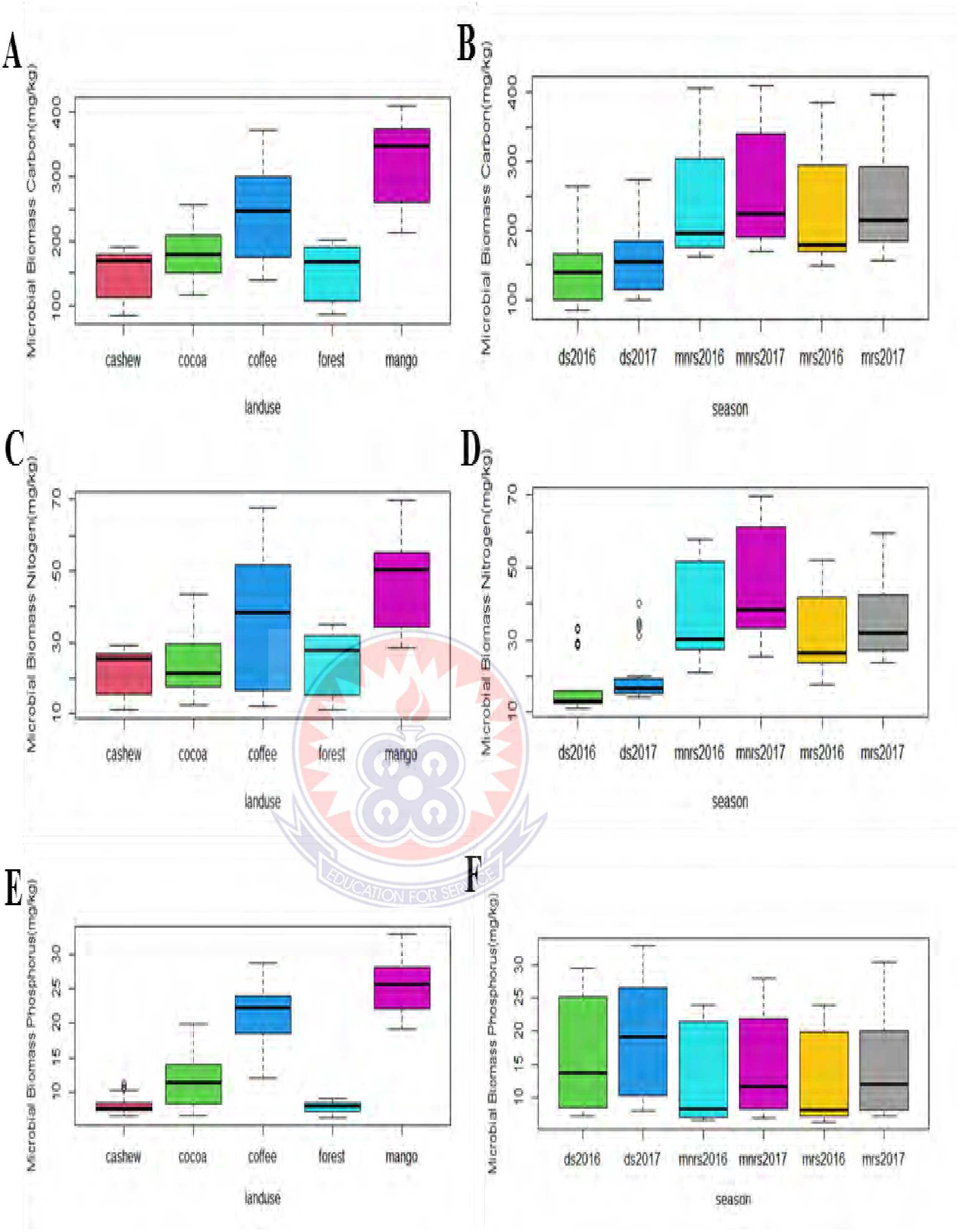

Figure 4. 15 Box plot of land use and seasonal microbial biomass carbon, nitrogen and phosphorus

4.5.2 Microbial biomass Nitrogen

Microbial biomass nitrogen under Mango plantation was the highest (47.32 mg/kg) followed by coffee plantation (35.63mg/kg), forest (24.79 mg/kg), cocoa (24.44 mg/kg) plantations with cashew plantation (22.28 mg/kg) recording the least (Figure

4.15c). The values for mango plantation and coffee plantation were significantly different ($p < 0.05$) from forest, cocoa plantation and cashew plantation. Cocoa plantation was no significantly different ($p < 0.05$) from both forest and cashew plantation; however, forest was significantly different from cashew plantation.

DS2016 (16.73 mg/kg) recorded the lowest soil microbial biomass nitrogen followed by DS2017 (20.04 mg/kg), MRS2016 (31.23 mg/kg), MRS2017 (35.97 mg /kg), MNRS2016 (36.91 mg/kg) while MNRS2017 (44.46mg/kg) recorded the highest (Figure 4.16d). MNRS2017, MRS2016, DS2017 and DS2016 were significantly different ($p < 0.05$) from each other. However, there was no significant difference ($p < 0.05$) between MRS2017 and MNRS2016. A similar trend was observed as seen in soil microbial biomass carbon where similar seasons like first and second dry seasons showed similar results (Figure 4.15. D).

There was an interaction between the land use and season on soil microbial biomass nitrogen.

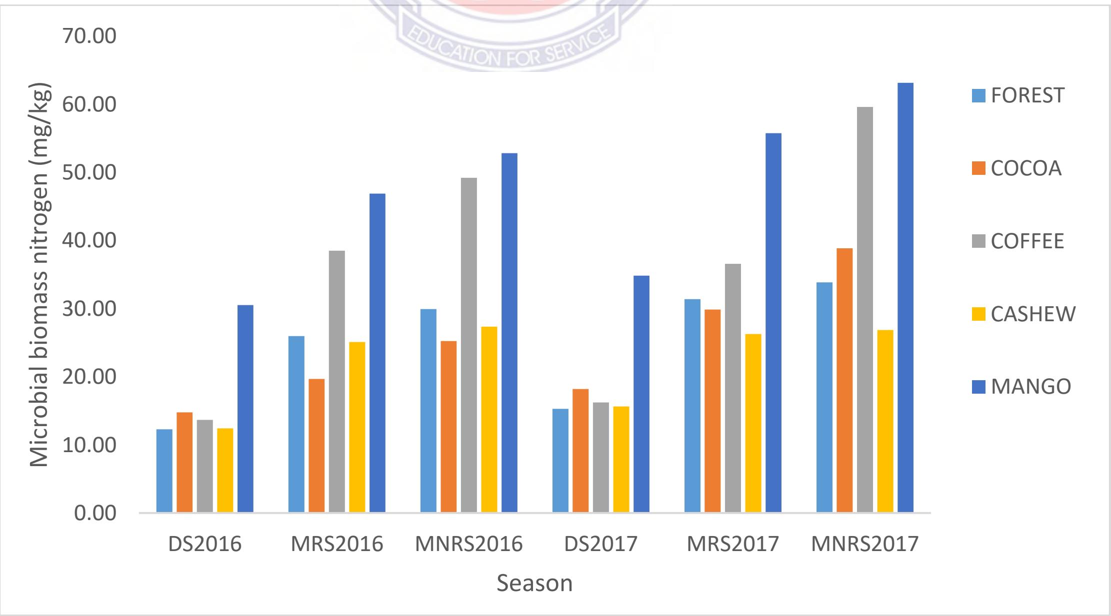

Figure 4.16 Land use and season interaction on soil microbial biomass nitrogen

Significant differences ($p < 0.05$) were observed among the different factor combinations, with mango×MNRS2017 recording the highest (63.14 mg/kg) soil microbial biomass nitrogen followed by coffee×MNRS2017 (59.59 mg/kg) while frorest×DS2016 (12.28 mg/kg) recorded the least value followed by cashew×DS2016 (12.48 mg/kg) (Figure 4.16). It as also observed that, mango conbinations recorded the highest soil microbial biomass nitrogen in all the six levels of season with coffee folloing while cashew combinations recorded the least value.

4.5.3 Microbial biomass Phosphorus

The least Microbial biomass Phosphorous was recorded under forest stand (7.89 mg/kg), followed by cashew plantation (8.18 mg/kg), cocoa plantation (11.85 mg/kg), coffee plantations (21.75mg/kg), while Mango plantation (25.5 mg/kg) recorded the highest (Figure 4.15e). All the different land uses were significantly different ($p < 0.05$) from each other, except forest stand and cashew plantation which were similar ($p < 0.05$) (Table 4.8).

MRS2016 (12.97 mg/kg) recorded the least microbial biomass phosphorous followed MNRS2016, (13.02 mg/kg) MRS2017 (14.75 mg/kg), MNRS2017 (14.75 mg/kg) and DS2016 (16.2 mg/kg), while DS2017 (18.45 mg/kg) recorded the highest (Figure 4.16.F). DS2017 and DS2016 were significantly different ($p < 0.05$) from all the other seasons. MRS2017 and MNRS2017 were similar ($p < 0.05$), but were significantly different ($p < 0.05$) from MRS2016 and MNRS2016. Also, microbial biomass phosphorus under MRS2016 and MNRS2016 were not significantly different ($p < 0.05$) from each other but were different from MRS2016 and MNRS2016.

There was an interaction between land use and season on microbial biomass phosphorous values.

Table 4.9 Land use and season interaction on microbial biomass phosphorus

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	8.00	13.11	24.21	8.57	27.13
MRS2016	6.98	7.51	21.15	7.69	21.53
MNRS2016	7.09	8.22	20.93	7.02	21.84
DS2017	8.67	18.21	26.06	10.66	28.63
MRS2017	8.03	12.20	17.17	7.75	28.61
MNRS2017	8.56	11.89	20.95	7.39	25.26
LSD 5%			1.987		
CV (%)			2.8		

Significant differences ($p < 0.05$) were observed among the different factor combinations with mango×DS2017 recording the highest (28.63 mg /kg) soil microbial biomass phosphorus followed by mango×MRS2017(28.61 mg/kg) while forest×MRS2016 (6.98 mg/kg) recorded the least value followed by (7.02 mg/kg). It as also observed that, mango conbinations recorded the highest soil microbial biomass phosphorus in all the six levels of season with coffee folloing (Table 4.9).

4.5.4 Microbial quotient carbon

The highest microbial quotient carbon was recorded under mango plantation (1.4394) followed by coffee plantation (1.0535 %), cocoa plantation (0.7796 %), and cashew plantation (0.6766 %) while forest stand (0.6385 %) recorded the least. Apart from forest and cashew plantation which were not significantly different ($p < 0.05$) from each other, all the other land uses were significantly different ($p < 0.05$) from each other (Table 4.10).

The highest microbial quotient carbon was recorded under MNRS2017 (1.0923 %), followed by MNRS2016 (1.0404 %), MRS2017 (1.0379 %), MRS2016 (0.9899), DS2017 (0.6914 %) with DS2016 (0.6532 %) having the least.

Table 4. 10 Land use and seasonal effect on soil microbial quotient C, N, P

	Microbial carbon quotient qCmic **(%)**	Microbial nitrogen quotient qNmic **(%)**	Microbial phosphorus quotient qPmic **(%)**
Land use			
Forest	0.6385	0.775	0.003149
Cocoa	0.7796	1.082	0.00482
Coffee	1.0535	0.847	0.008172
Cashew	0.6766	0.525	0.003029
Mango	1.4394	2.508	0.009489
F pr	0.001	0.001	0.001
LSD 5%	0.0406	0.0797	0.0003236
Season			
DS2016	0.6532	0.696	0.006271
MRS2016	0.9899	1.156	0.004979
MNRS2016	1.0404	1.348	0.00496
DS2017	0.6914	0.783	0.007039
MRS2017	1.0379	1.329	0.005586
MNRS2017	1.0923	1.571	0.005556
F pr	0.001	0.001	0.001
LSD 5%	0.04448	0.0874	0.0003545
Land use ×Season			
F pr	0.001	0.001	0.001
LSD 5%	0.09946	0.1953	0.0007927
CV	3.1	3.7	4

Similar seasons like first and second dry seasons, first and second major rainy seasons and the first minor rain season recorded similar results (Table 4.10) MRS2016 was not significantly different ($p < 0.05$) from DS2016, DS2017, MRS2017 and MNRS2016. Although MNRS2017 was not significantly different ($p < 0.05$) from MNRS2016 MRS2017 it was significantly different ($p < 0.05$) from all the other seasons. It was also observed that, DS2016 and DS2017 were not significantly different from each other but were significantly different from MRS2016, which was also significantly different from MNRS2016 and MNRS2017 who were not significantly different from each other. (Table 4.10).

An interaction between land use and season on microbial quotient carbon were observed Table 4.10).

Table 4.11 Land use and season interaction on microbial quotient carbon

			Land use		
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	0.4171	0.6032	0.6929	0.4349	1.1182
MRS2016	0.6836	0.7174	1.1841	0.7804	1.5840
MNRS2016	0.7356	0.8293	1.1841	0.7918	1.6614
DS2017	0.4574	0.6849	0.7422	0.5081	1.0642
MRS2017	0.7629	0.8972	1.1519	0.7592	1.6183
MNRS2017	0.7746	0.9457	1.3660	0.7851	1.5903
LSD 5%			0.0099		
CV (%)			3.1		

A Significangt difference was observed among the different factor combination with mango×MNRS2016 recording the highest (1.661 %) microbial quotient carbon value followed by mango×MRS2017 (1.618 %) while the least value as recored by forest×DS2016 (0.417 %) followed by forest×DS2017(0.457 %). It was observed that in all the different levels of season mango combinations recorded the highest value of microbial quotient carbon (Table 4.11).

4.5.5 Microbial quotient nitrogen

The least microbial quotient nitrogen was recorded under cashew plantation (0.525 %) followed by forest (0.775 %), coffee plantation (0.847 %) and cocoa plantation (1.082 %) while Mango plantation (2.508 %) recorded the highest microbial quotient nitrogen. Forest and coffee plantation were not significantly different ($p < 0.05$) from each other but were significantly different ($p < 0.05$) from all the other land uses (Table 4.10).

MNRS2017 (1.571 %) recorded the highest microbial quotient nitrogen value while DS2016 (0.696 %) recorded the least microbial quotient nitrogen. MNRS2017 and MRS2016 were significantly different ($p < 0.05$) from all the other land uses. However, DS2016 and DS2017 were not significantly different ($p < 0.05$) from each other just as MRS2017 and MNRS2016 were not significantly different ($p < 0.05$) from each other.

There was an interaction between land use and seasonal microbial quotient nitrogen values (Table 4.10).

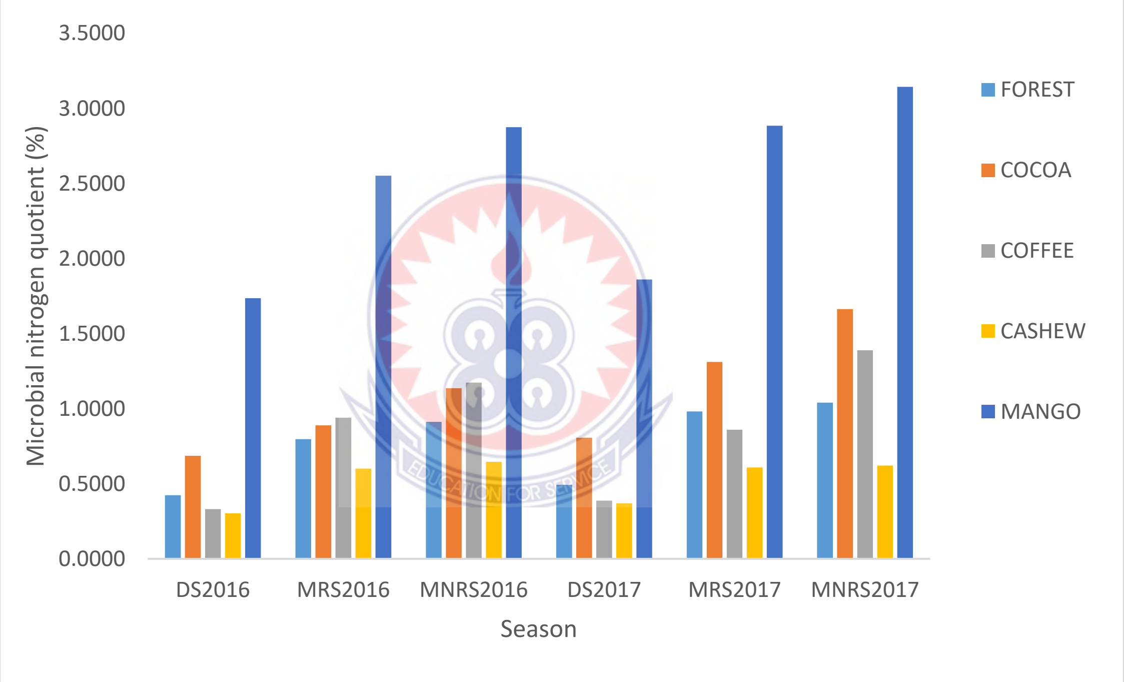

Figure 4.17 Land use and season interaction on soilmicrobial quotient nitrogen

It was observed that significant differences ($p < 0.05$) existed among the different factor combinations, with mango×MNRS2017 recording the highest (3.143 %) value and closely followed by mango×MRS2017 (2.884 %) while cashew×DS2016 (0.303 %) recorded the least microbial quotient nitrogen value followed by coffee×DS2016 (0.330 %) (Figure 4.17). It was observed that in all the different levels of season mango combinations recorded the highest value of microbial quotient carbon while cashewcombinations recorded the least microbial quotient nitrogen in all the different levels of season.

4.5.6 Microbial quotient phosphorous

The highest microbial quotient phosphorous value was recorded under mango plantation (0.009489 %) while cashew plantation (0.003029 %) recorded the least microbial quotient phosphorous followed by forest stand (0.003149 %), cocoa plantation (0.00482 %), and coffee plantations (0.008172 %) (Table 4.10). But for cashew plantation and forest which were not significantly different ($p < 0.05$) from each other, all the other land uses were significantly different ($p < 0.05$) from each other.

MNRS2016 (0.00496 %) recorded the least microbial quotient phosphorous followed by MRS2016 (0.004979 %), MNRS2017 (0.005556 %), MRS2017 (0.005586 %) and DS2016 (0.006271 %) while DS2017 (0.007039 %) recorded the highest. DS2016 and DS2017 were significantly different ($p < 0.05$) from all the other seasons. However, MRS2017 and MNRS2017 were not significantly different ($p < 0.05$) from each other but were significantly different from MRS2016 and MNRS2016 which were not significantly different ($p < 0.05$) from each other.

There was an interaction between land use and seasonal microbial quotient phosphorous values (Table 4.10).

The results showed that, there were significant differences ($p < 0.05$) among the different factor combinations, with mango×DS2017 (1.0106 %) and mango×MRS2017 (1.0106 %) jointly recording the highest soil microbial quotient phosphorus while cashew×MRS2016 recording the least (0.0026 %) value followed jointly by cashew×MRS2017 (0.0028 %) and forest×MRS2016 (0.0028 %).

Table 4.12 Land use and season interaction on microbial quotient phosphorus

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	0.0033	0.0054	0.0093	0.0032	0.0102
MRS2016	0.0029	0.0031	0.0080	0.0029	0.0081
MNRS2016	0.0028	0.0034	0.0079	0.0026	0.0081
DS2017	0.0034	0.0075	0.0097	0.0039	0.0106
MRS2017	0.0032	0.0050	0.0064	0.0028	0.0106
MNRS2017	0.0033	0.0047	0.0077	0.0027	0.0093
LSD 5%	0.0008				
CV (%)	4.0				

Again, it was revealed that mango combinations recorded the highest soil microbial quotient phosphorus in all the different levels of season while cashew combinations consitantly recorded the least value (Table 4.12).

4.5.7 Soil microbial biomass C/N ratio

The highest microbial biomass carbon to microbial biomass nitrogen ratio was recorded in the coffee plantation (8.154), followed by cocoa plantation (8.114), mango (6.649) and cashew (6.924) plantations, while the forest stand (6.392) recorded the least (Table 4.13).

The results indicated that while forest was significantly different ($p < 0.05$) from all the other land uses. Cashew plantation and mango plantation were not significantly different ($p < 0.05$) from each other. However, they were different from cocoa plantation and coffee plantation which were also not significantly different ($p < 0.05$) from each other.

Table 4. 13 Land use and seasonal effect on soil microbial biomass C/N, C/P, N/P ratios

	Microbial carbon/nitrogen Cmic/Nmic	Microbial carbon/phosphorus Cmic/Pmic	Microbial Nitrogen/phosphorus Nmic/Pmic
Land use			
Forest	6.392	19.774	3.09
Cocoa	8.114	16.987	2.397
Coffee	8.154	11.937	1.731
Cashew	6.924	19.357	2.95
Mango	6.949	13.061	1.937
F pr	0.001	0.001	0.001
LSD 5%	0.2422	0.3471	0.086
Season			
DS2016	8.856	9.68	1.237
MRS2016	7.301	19.422	2.778
MNRS2016	6.494	20.923	3.297
DS2017	8.195	9.391	1.252
MRS2017	7.054	18.552	2.727
MNRS2017	5.941	19.372	3.235
F pr	0.001	0.001	0.001
LSD 5%	0.2653	0.3803	0.0942
Land*Season			
F pr	0.001	0.001	0.001
LSD 5%	0.5932	0.8503	0.2107
CV	1	0.6	0.8

The results showed that MNRS2017 (5.941) recorded the least value of soil microbial biomass C/N ratio followed by MNRS2016 (6.494), MRS2017 (7.054) MRS2016 (7.301) and DS2017 (8.195) with DS2016 (8.856) recording the highest (Table 4.13). The results showed that similar seasons like first and second dry seasons, first and second major rain seasons and first and second minor rain seasons were not significantly differently ($p < 0.05$) from each other. However, the dry seasons, major rainy seasons and minor rainy seasons were significantly different ($p < 0.05$) from different Seasons. There was an interaction between land use and season values of microbial biomass carbon to microbial biomass nitrogen ratio (Table 4.13).

Table 4.14 Land use and season interaction soil mirobial biomass C/N ratio

	Land use					
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO	Mean
DS2016	7.632	9.526	11.714	7.616	7.791	8.856
MRS2016	6.370	8.655	7.322	6.663	7.495	7.301
MNRS2016	5.540	7.632	5.603	6.530	7.164	6.494
DS2017	7.372	8.709	10.798	7.386	6.709	8.195
MRS2017	5.832	8.362	7.712	6.637	6.727	7.054
MNRS2017	5.607	5.802	5.775	6.711	5.808	5.941
Mean	6.392	8.114	8.154	6.924	6.949	
LSD (0.05) Land use			0.242			
LSD (0.05) Season			0.265			
LSD (0.05) Land use ×Season			0.593			
CV (%)			0.6			

Significant differences ($p < 0.05$) were observed among the different factor combinations of land use and season with cashew×DS2016 recording the highest (5.540) value of microbial biomass C/N ratio followed by mango×DS2017 (5.607) while forest×MNRS2016 recorded the least value followed by forest×MNRS2017(Table 4.14).

4.5.8 Soil microbial biomass C/P ratio.

The results indicated that coffee (11.94) recorded the least value for soil microbial biomass carbon to soil microbial biomass phosphorous ratio followed by mango plantation (13.06), cocoa plantation (16.99) and cashew plantation (19.36), while forest (19.77) recorded the highest (Table 4.13). Forest and cashew plantation were significantly different ($p < 0.05$) from all the other land uses, but were not significantly different ($p < 0.05$) from each other.

The results indicate that DS2017 (9.39) recorded the least value for soil microbial biomass carbon to soil microbial biomass phosphorous ratio followed by DS2016 (9.68), MRS2017 (18.55) MNRS2017 (19.37) and MRS2016 (19.42), while

MNRS2016 (20.92) recorded the highest. DS2017 and DS2016 were significantly different ($p < 0.05$) from all the other seasons but were not significantly different ($p < 0.05$) each other (Table 4.13). There was an interaction between land use and season on soil microbial biomass carbon to soil microbial biomass phosphorous ratio values (Table 4.13). Significant differences ($p < 0.05$) were observed among the different factor combinations of land use and season with cashew×MNRS2016 (25.600) recording the highest value of microbial biomass C/P ratio closely followed by forest×MNRS2016 (24.610) while coffee×DS2017 (6.663) recorded the least value followed by coffee×DS2017 (6.674).

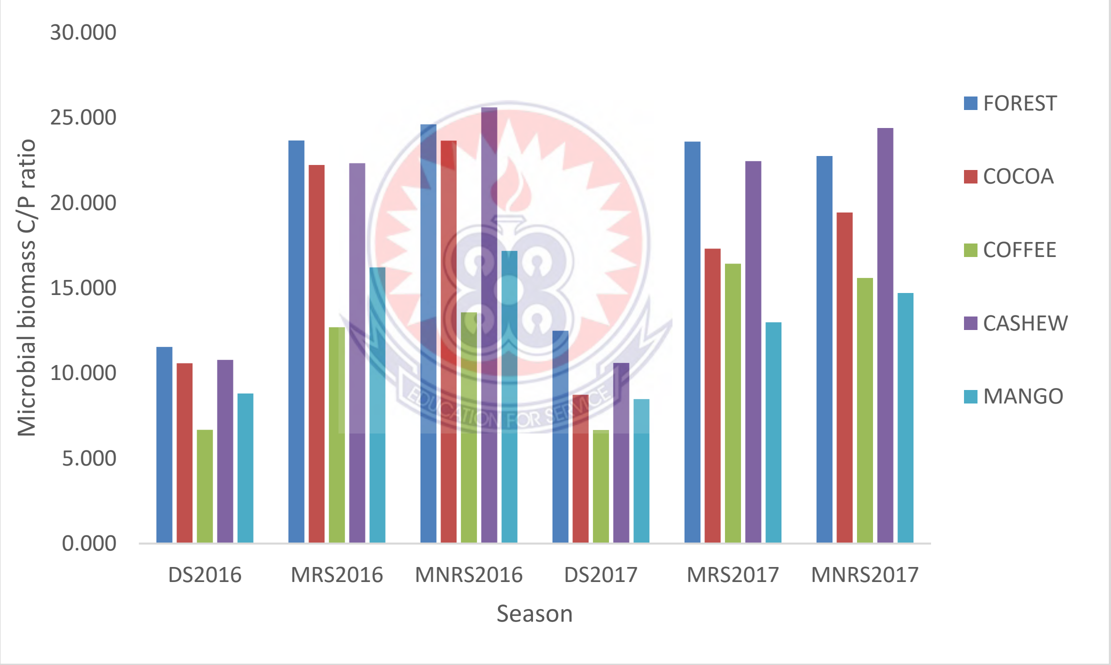

Figure 4.18 **Land use and season interaction** ***on microbial C/P ratio***

4.5.9 Soil microbial biomass N/P ratio

The least value of soil microbial biomass nitrogen to Soil microbial biomass phosphorous ratio was recorded under coffee plantation (1.73) followed by mango plantation (1.94), cocoa plantation (2.40), and cashew plantations (2.95) while forest stand (3.09) recorded the highest value. All the land uses were significantly different ($p < 0.05$) from each other (Table 4.13).

The highest soil microbial biomass nitrogen to soil microbial biomass phosphorous ratio value was recorded by MNRS2016 (3.30), followed by MNRS2017 (3.24), MRS2016 (2.78), MRS2017 (2.73), and DS2017 (1.25) while DS2016 (1.24) recorded the least value. It was observed that similar seasons, thus first and second dry seasons, first and second major rain seasons and first and second minor rain season were not significantly differently ($p < 0.05$) from each other but were significantly different ($p < 0.05$) from the other seasons (Table 4.13). There was an interaction between the land use and seasonal soil microbial biomass nitrogen to soil microbial biomass phosphorous ratio values.

Table 4.15 Land use and season interaction on soil microbialbiomass N/P ratio

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	1.416	1.326	0.635	1.639	1.168
MRS2016	3.621	2.662	1.765	3.587	2.253
MNRS2016	4.440	3.271	2.471	3.844	2.459
DS2017	1.682	1.130	0.661	1.512	1.273
MRS2017	3.707	2.504	2.130	3.389	1.906
MNRS2017	3.675	3.489	2.722	3.730	2.560
LSD 5%			0.211		
CV (%)			0.8		

It was observed that significant differences ($p < 0.05$) existed among the different factor combinations of land use and season of soil microbial biomass N/P ratio, with forest×MNRS2016 recording the highest (4.440) value, followed by cashew×MNRS2016 (3.844) while coffee×DS2016 (0.635) recorded the least value followed by coffee×DS2016 (0.661) (Table 4.15).

4.6 Soil chemical properties

Results of the chemical characteristics of the soils under the different land uses and seasons are presented in Table 4.16

Table 4. 13 Land use and seasonal influence on some soil chemical properties

	N	P	Exchangeable Bases (cmol_c/kg)			pH
	(%)	(mg/kg)	K	Ca	Mg	
Land use						
Forest	0.317	25.053	0.284	5.391	2.159	6.713
Cocoa	0.225	24.663	0.258	5.669	0.023	6.707
Coffee	0.420	26.667	0.415	3.220	2.194	7.075
Cashew	0.423	27.038	0.116	0.823	0.006	6.728
Mango	0.188	26.865	0.134	3.330	1.050	7.120
Fpr	0.001	0.001	0.001	0.001	0.001	0.001
LSD (5%)	0.004	0.271	0.013	0.059	0.017	0.058
Season						
DS2016	0.301	25.652	0.239	3.659	1.076	6.860
MRS2016	0.312	25.772	0.240	3.662	1.074	6.854
MNRS2016	0.316	26.014	0.244	3.672	1.084	6.873
DS2017	0.314	26.121	0.239	3.697	1.098	6.865
MRS2017	0.320	26.265	0.247	3.711	1.089	6.860
MNRS2017	0.325	26.520	0.240	3.706	1.097	6.900
Fpr	0.001	0.001	0.791	0.435	0.053	0.752
LSD (5%)	0.005	0.296	0.014	0.064	0.019	0.063
Land use*season						
Fpr	0.001	0.99	0.554	0.977	0.625	1
LSD (5%)	0.010	0.663	0.031	0.144	0.042	0.142
CV (%)	0.9	1.4	2.5	1.3	1.2	0.4

4.6.1 Total nitrogen

Nitrogen values were significantly different ($p < 0.05$) among the different land uses. Coffee plantation and cashew plantation were not significantly different ($p < 0.05$) from each other, but were significantly different ($p < 0.05$) from forest, cocoa plantation and mango plantation (Table 4.16).

Cashew (0.423 %) recorded the highest soil total nitrogen followed by coffee plantation (0.420 %), forest (0.317 %) and cocoa plantation (0.225 %) while mango plantation (0.188 %) recorded the lowest (Table 4.16). Generally, soil total nitrogen was moderate to high (Appendix A).

It was observed that, there was significant differences ($p < 0.05$) among the different seasons. MNRS2017 (0.325 %) recorded the highest soil total nitrogen while DS2016 (0.301 %) recorded the lowest (Table 4.16).

Table 4.17 Interaction of land use and season on total nitrogen

	Land use				
Season	FOREST	COCOA	COFFEE	CASHEW	MANGO
DS2016	0.290	0.216	0.414	0.410	0.176
MRS2016	0.326	0.222	0.410	0.418	0.184
MNRS2016	0.328	0.222	0.420	0.424	0.184
DS2017	0.310	0.226	0.420	0.424	0.188
MRS2017	0.320	0.228	0.426	0.432	0.194
MNRS2017	0.326	0.234	0.430	0.432	0.202
LSD 5%	0.010				
CV (%)	0.9				

It was observed that, similar seasons, thus dry seasons, major rain seasons and minor rain seasons recorded similar values in different years.

There was an interaction between land use and season on total nitrogen (Table 4.16). It was observed that significant differences ($p < 0.05$) existed among the different factor combinations of land ues and season with cashew×MRS2017 (0.432 %) and cashew×MNRS2017 (0.432 %) jointly recording the highest soil taotal nitrogen while mango×DS2016 recorded the lowest (0.176 %) value followed by mango×MRS2016 (0.184 %). (Table 4.17)

4.6.2 Available phosphorus

Soil available phosphorus varied significantly ($p < 0.05$) among the land uses and ranged from 27.038 mg/kg to 24.663 mg/kg, with cashew plantation and cocoa plantation recording the highest and lowest respectively (Table 4.16)

It was observed that, cashew plantation and mango plantation were not significantly different ($p < 0.05$) from each other, but they were significantly different ($p < 0.05$) from forest, cocoa plantation and coffee plantation, which were also significantly different ($p < 0.05$) from each other (Table 4.16). Generally, all the land use recorded high soil available phosphorus values (Appendix A).

The highest soil available phosphorus was recorded under MNRS2017 (26.520 mg/kg), while DS2016 (25.652 mg/kg) recorded the lowest (Table 4.16). It was observed that different seasons were significantly ($p < 0.05$) different from each other. Again, it was observed that MRS2017 and MNRS 2017 were not significantly different ($p < 0.05$) from each other but were significantly different ($p < 0.05$) from DS2016, MRS2016 and MNRS2016. Also, DS2017 and MNRS2016 were not significantly different ($p < 0.05$) from each other (Table 4.16).

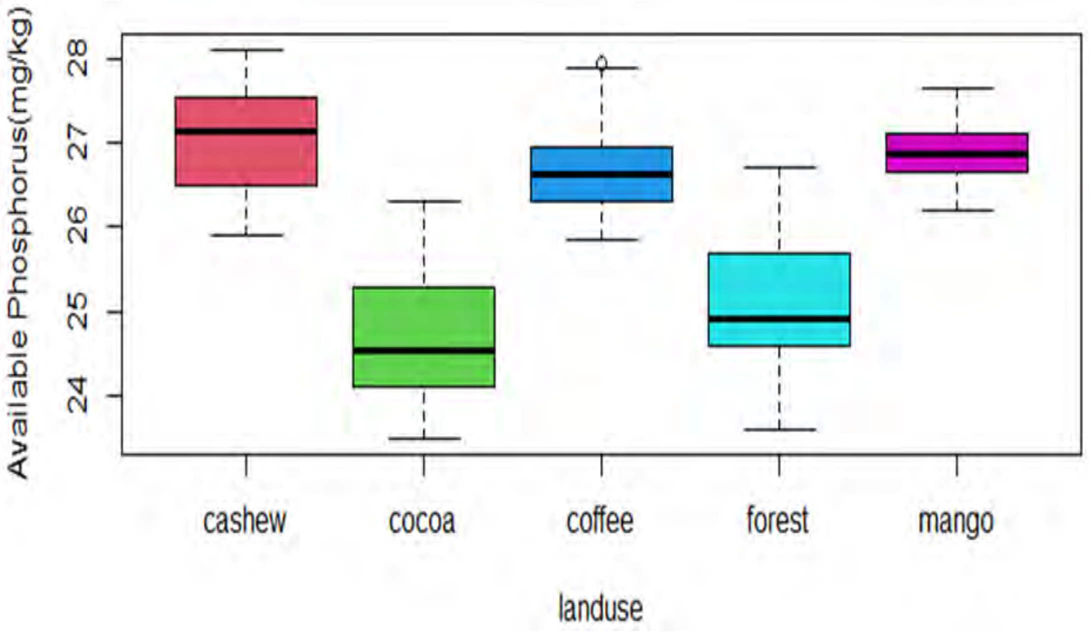

Figure 4. 19 Box plot of land use effect on available phosphorus

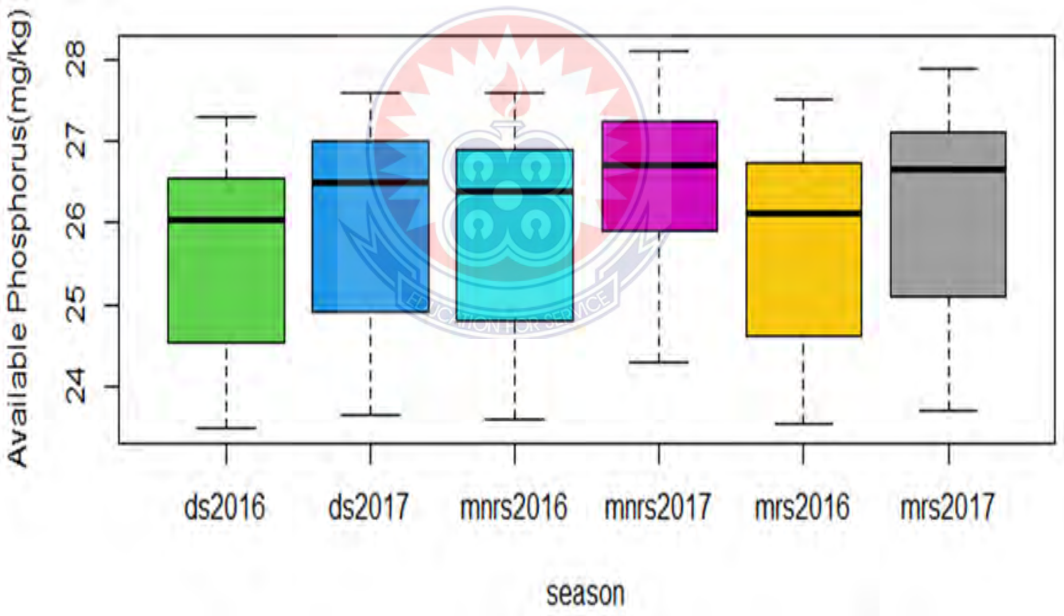

Figure 4. 20 Box plot of seasonal effect on available phosphorus

There was a general increase from DS2016 to MNRS2017. It was also observed that, minor rain seasons (MNRS2016, MNRS2017) recorded the highest values within a year followed by major rain seasons (MRS2016, MRS2017), while the dry seasons (DS2016, DS2017) recorded the lowest soil available phosphorus.

Thus MNRS2016>MRS2016>DS2016 and MNRS2017>MRS2017>DS2017 (Figure 4.20). There was no interaction between the land use and season on available phosphorus (Table 4.16).

4.6.3 Basic exchangeable bases (K^+, Ca^{2+}, Mg^{2+})

There were significant ($p < 0.05$) differences in K^+, Ca^{2+}, Mg^{2+} among the different land uses. Coffee plantation recorded the highest (0.415 $cmol_c/kg$) exchangeable $K^{+,}$ while cashew plantation (0.116 $cmol_c/kg$) recorded the least (Table 4.16). It was observed that coffee plantation > forest > cocoa plantation > mango plantation > cashew plantation.

A similar trend was observed in both exchangeable calcium and magnesium, where coffee plantation recorded the highest Ca^{2+} (3.220 $cmol_c/kg$) value, the highest Mg^{2+} (2.194 $cmol_c/kg$), while cashew plantation recorded the least for Ca^{2+} (0.823 $cmol_c/kg$) and Mg^{2+} (0.006 $cmol_c/kg$), respectively.

The resultsfor the exchangeable Ca^{2+} of the different land uses showed that cocoa plantation was significantly different ($p < 0.05$) from all the other different land uses. However, coffee plantation and mango plantation were not significantly different ($p < 0.05$) from each other, but were significantly different ($p < 0.05$) from cashew plantation and forest (Table 4.16).

Similarly, the exchangeable magnesium of the different land uses indicated that, cocoa plantation and cashew plantation were not significantly different from each other but were significantly lower than mango plantation, forest and cashew plantation which were also significantly different from each other (Table 4.16).

There were no significant ($p < 0.05$) difference among the seasons for K^+, Ca^{2+} and Mg^{2+} neither was there an interaction between the land use and season on all the measured exchangeable bases (K^+, Ca^{2+} and Mg^{2+}) (Table 4.6).

4.6.4 Soil pH

The pH was neutral to slightly alkaline and ranged from 6.707 to 7.120 (Appendix A) with mango plantation recording the highest value, while cocoa plantation recorded the least value. There were significant ($p < 0.05$) differences among the land uses. It was observed that pH in the mango plantation > coffee plantation > cashew plantation > forest > cocoa plantation. Forest, cocoa plantation, and cashew plantation were not significantly ($p < 0.05$) different from each other, but were significantly ($p < 0.05$) different from Coffee plantation and Mango plantation who were not significantly different from each other (Table 4.16).

It was observed that, pH values among the different seasons were not significantly different from each other. Also, there was no interaction between the land use value and season values (Table 4.16).

4.7 Relationships among soil physical properties, hydraulic properties, chemical properties, carbon dynamics and soil microbial dynamics.

The correlation results between bulk density and some soil hydro-physical properties and soil organic carbon are illustrated in Figure 4.22.

Generally, there was significant negative relationship between bulk density and aggregate stability, total porosity, steady state infiltrability, infiltration amount and soil organic carbon. The r ranged from -0.21 to -1 while the p values were $p = 2.2^{-16}$ to 0.0083 (Figure 4.22). The correlation between bulk density and soil carbon stock was however significantly positive with a $r = 0.92$ and $p = 2.2^{-16}$

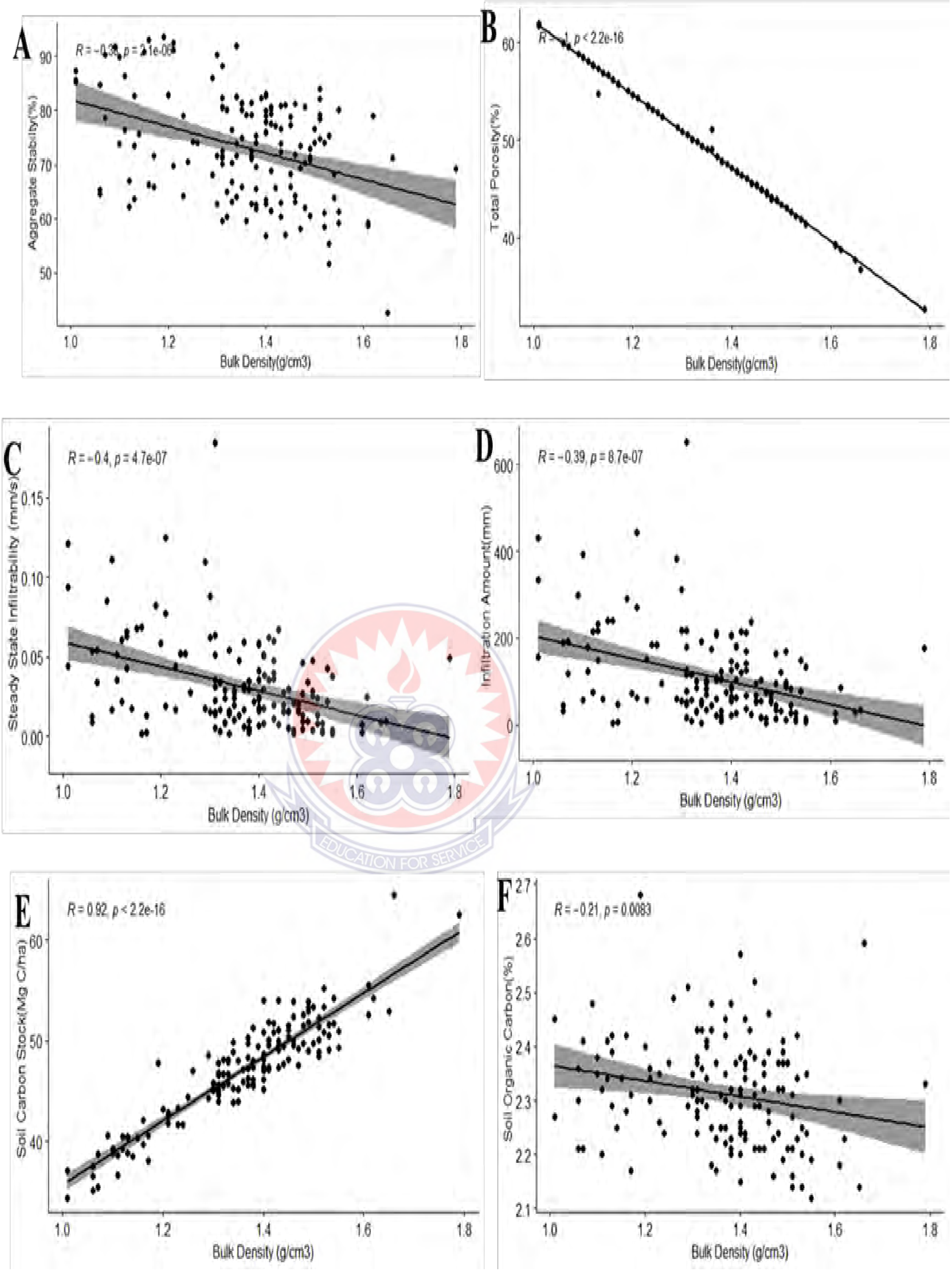

Figure 4. 3 Correlation between bulk density and aggregate stability, total porosity, steady state infiltrability, infiltration amount, soil carbon stocks, soil organic carbon

Correlation between bulk density and A= Aggregate stability, B= Total porosity, C=Steady state infiltrability, D=Infiltration amount, E= Soil carbon stock and F=Soil organic carbon.

From Figure 4.22, shows the correlation between litter fall and aggregate stability, infiltration amount and steady state infiltrability were significantly positive (p = 0.00042 to p = 0.0032). Their r ranged from r = 0.24 to r= 0.28. The correlation between litter fall and available phosphorus, microbial biomass nitrogen and microbial biomass carbon were however significantly negative correlated (p = 2.4^{-10} to p = 0.011: r = -0.21 to r = -0.45)

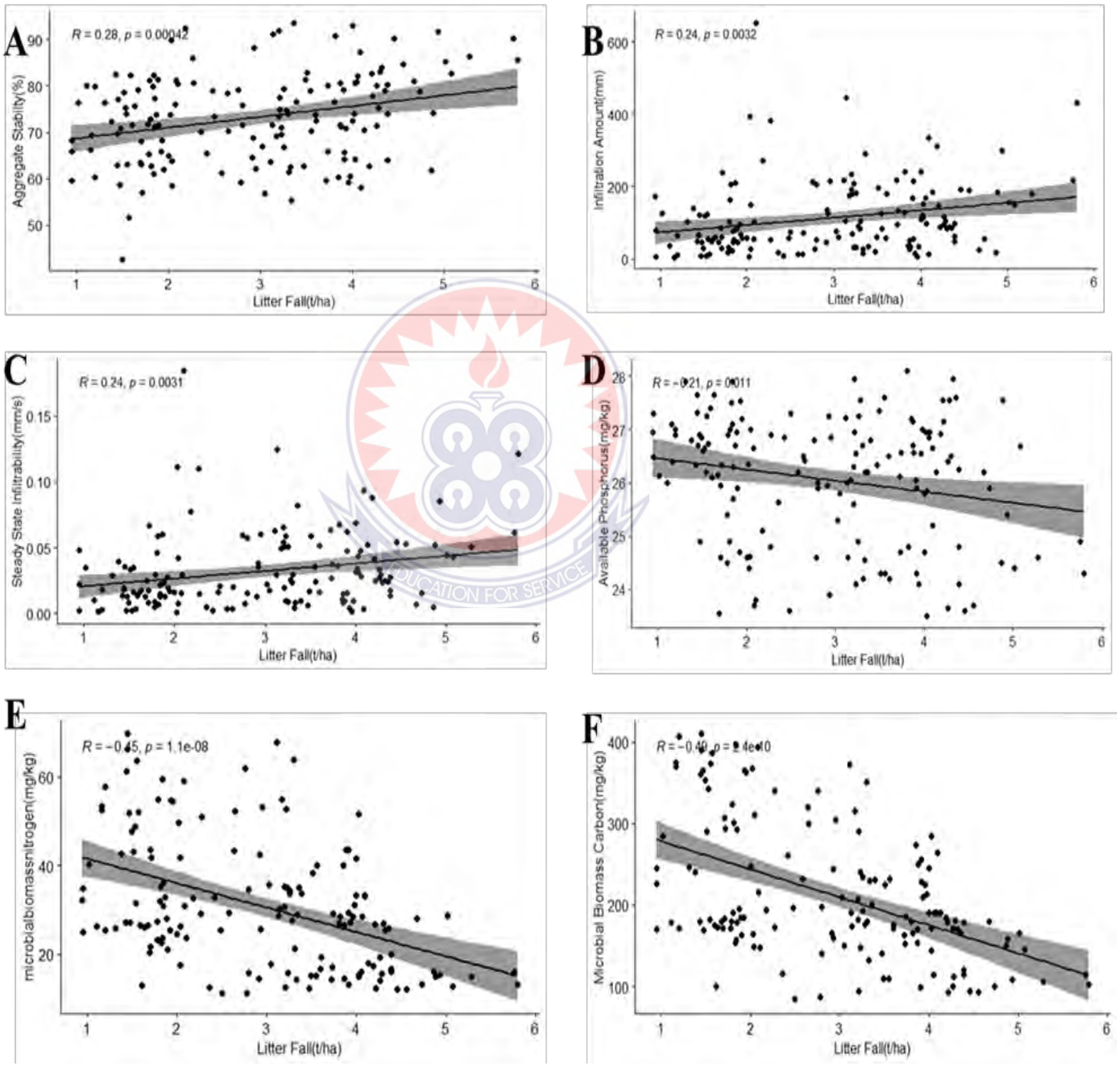

Figure 4. 22 Correlation between litter fal and aggregate stability, cumulative infiltration amount, steady state infiltrability, available phosphorus, microbial biomass nitrogen, microbial biomass carbon

Correlation between litter fall and A=Aggregate stability, B=Infiltration amount, C=Steady state infiltrability, D=Available phosphorus, E=Microbial biomass nitrogen, F=Microbial biomass carbon

There was generally a significantly ($p = 1.1^{-05}$ to $p = 0.028$) positive correlation between soil organic carbon and aggregate stability, bulk density, carbon stock, infiltration amount and saturated hydraulic conductivity ($r = 0.18$ to $r = 0.41$), (Figure 4.23). Soil microbial biomass C: N ratio unlike, aggregate stability, bulk density, carbon stock, infiltration amount and saturated hydraulic conductivity was significantly negatively correlated to soil organic carbon ($p = 0.0099$: $r = -21$).

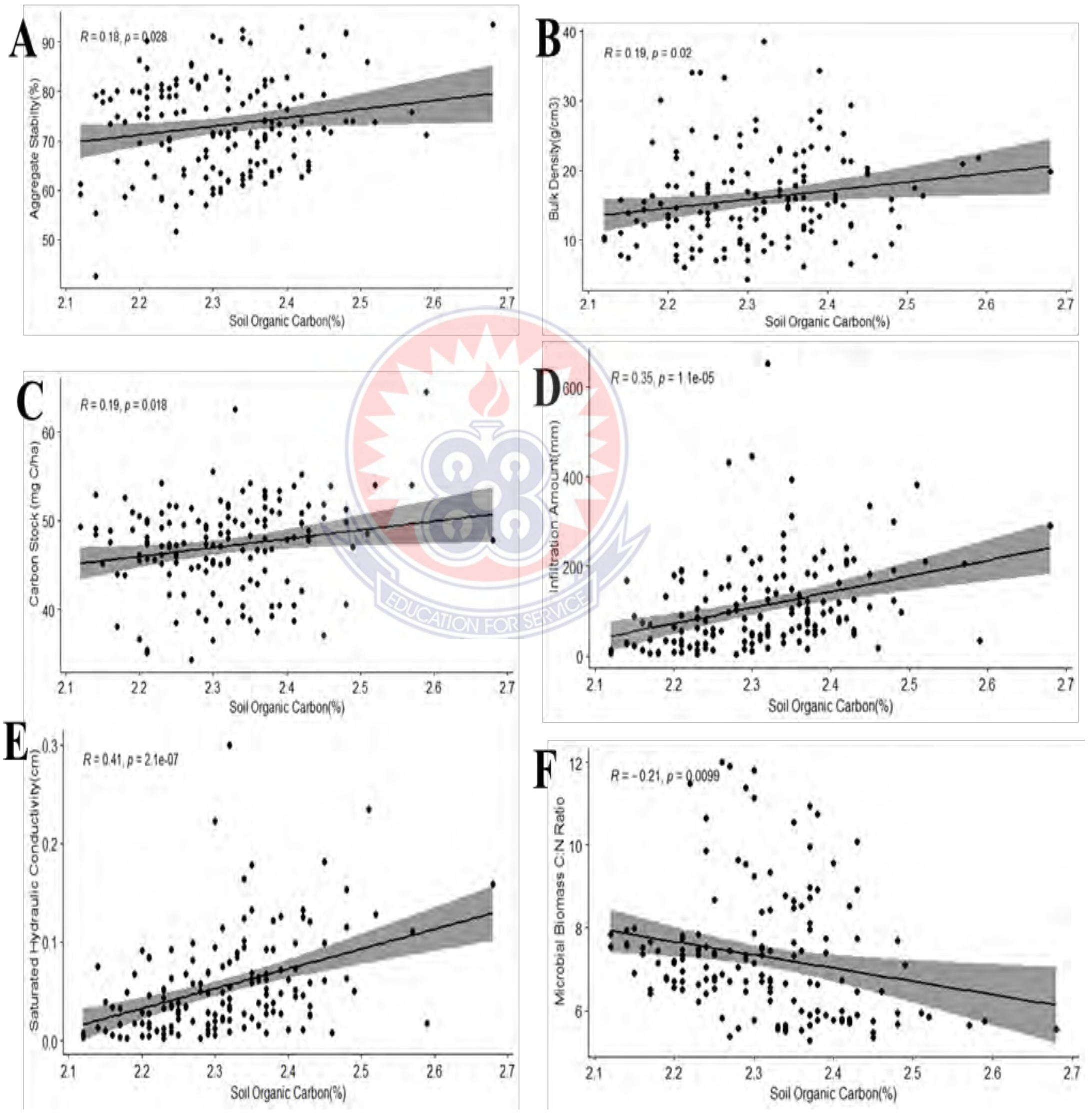

Figure 4. 23 Correlation between soil organic carbon and aggregate stability, bulk density, carbon stock, cumulative infiltration amount, saturated hydraulic conductivity, microbial biomass C:N ratio

Correlation between soil organic carbon and A =Aggregate stability, B=Bulk density, C=Carbon stock, D= Infiltration amount, E=Saturated hydraulic conductivity, F=Microbial biomass C: N ratio

From figure 4.24, a positive correlation was found between available phosphorus and soil microbial biomass phosphorus ($p = 1.1^{-05}$: $r = 0.35$) and microbial quotient phosphorus ($p = 0.00037$: $r = 0.29$). Microbial C: P ratio ($p = 0.0013$: $r = 0.26$) and Microbial N: P ratio ($p = 0.00025$: $r = 0.29$) correlated positively but weakly with soil organic carbon. However, a significantly negative correlation was found between total nitrogen and microbial biomass nitrogen ($p = 0.0037$: $r = -0.24$) and microbial quotient nitrogen ($p = 2.2^{-16}$: $r = -0.67$).

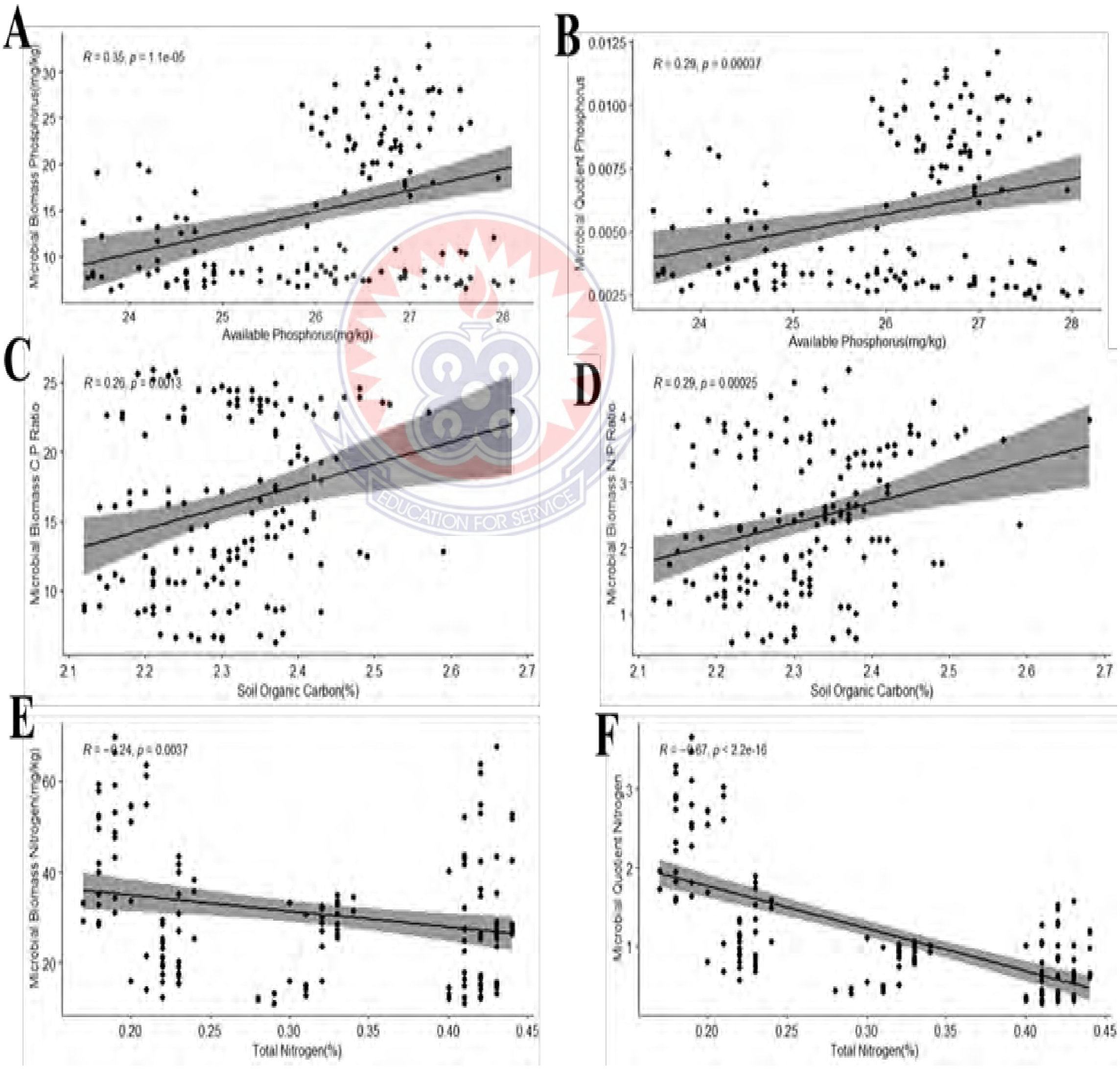

Figure 4. 24 Correlation between available phosphorus and MBP, qMBP: soil organic carbon and MBC, qMBC: total nitrogen and MBN, qMBN

Correlation between available phosphorus and A=MBP, B=qMBP: soil organic carbon and C=MBC, D=qMBC: total nitrogen and E=MBN, F=qMBN

Infiltration amount showed a positive relationship with sorptivity ($p < 2.2^{-16}$: r = 0.94) (Figure 4.25). A significantly negative correlation was observed between soil aggregate stability and microbial biomass carbon ($p = 1.5^{-08}$: r = -0.44) (Figure 4.26).

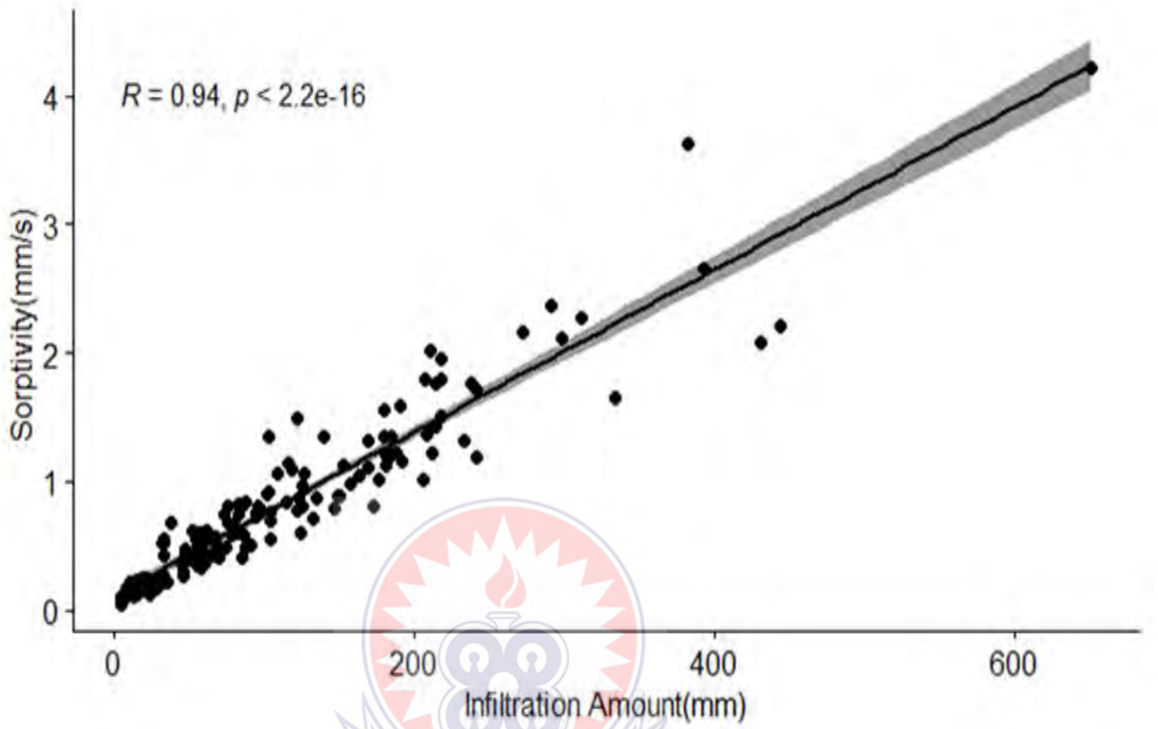

Figure 4. 25 Correlation between cumulative infiltration amount and sorptivity

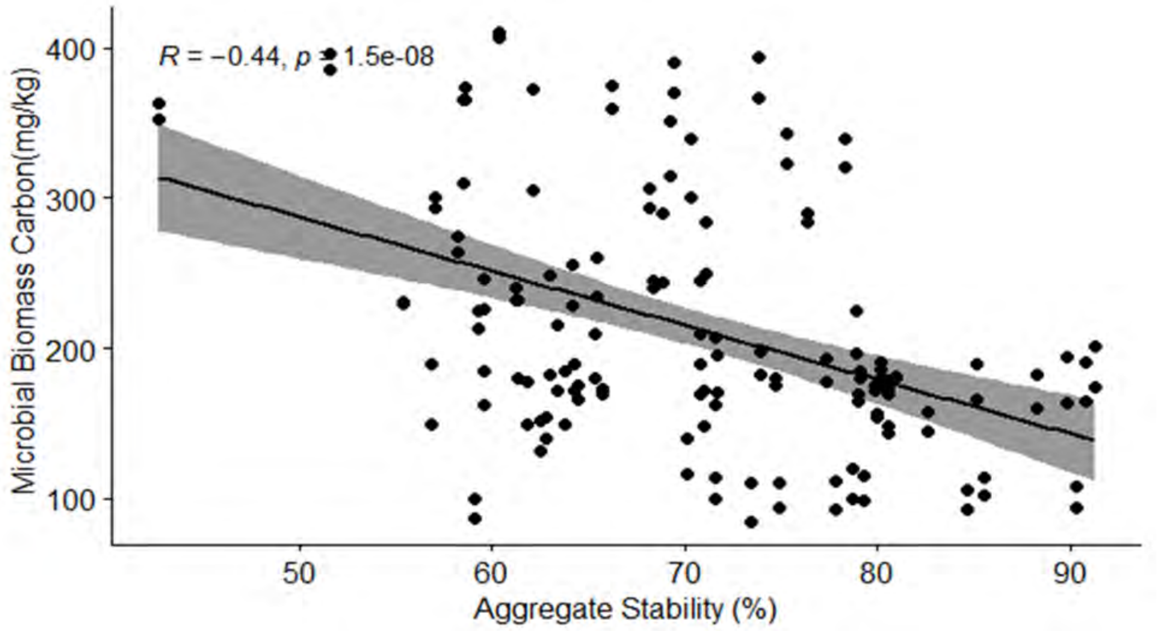

Figure 4. 26 Correlation between aggregate stability and microbial biomass carbon

Aggregate stability showed a positive correlation with saturated hydraulic conductivity (p = 3.7^{-08}: r = 0.43) (Figure 4.28)

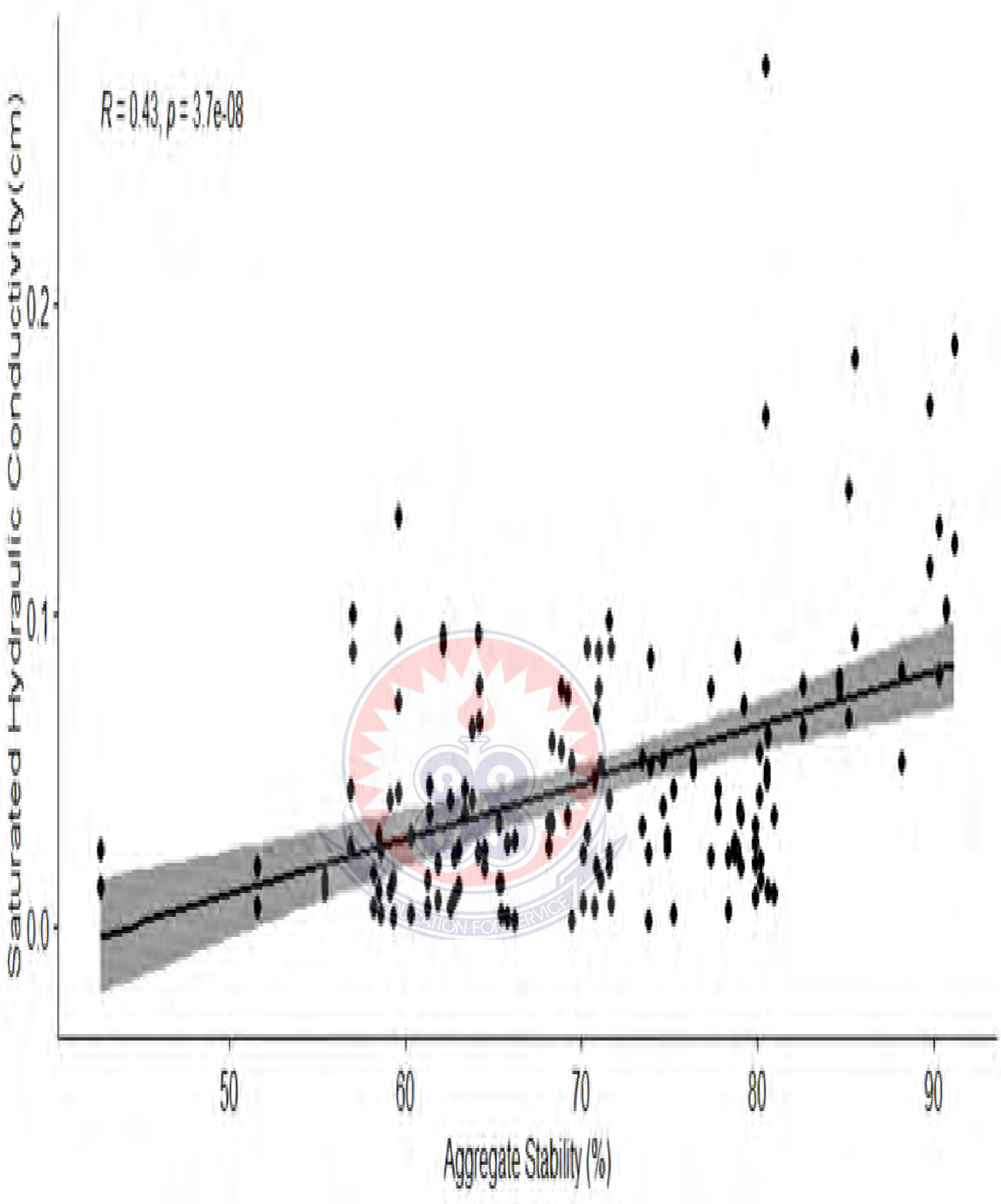

Figure 4. 27 Correlation between aggregate stability and saturated hydraulic conductivity

Table 4. 18 Relationship between litter fall and some soil physical, hydrological and carbon parameters

x	**y**	**regression equation**	**F pr**	**%var accounted**	**SE**
	Physical properties				
Litter Fall	*Aggregate stability*	$y = 66.37 + 2.32x$	0.001	7.5	9.26
	Total porosity	$y = 46.87 + 0.639x$	0.099	1.2	5.54
	Bulk density	$y = 1.4123 - 0.0184x$	0.073	1.5	0.15
	Hydrological				
Litter Fall	*Infiltration rate*	$y = 0.01467 + 0.00565x$	0.003	5.1	0.027
	Sorptivity	$y = 0.495 + 0.1292x$	0.034	2.3	0.872
	Saturated hydraulic conductivity	$y = 0.0353 + 0.00686x$	0.044	2.1	0.049
	Carbon dynamics				
Litter Fall	*Carbon sequestration* (C Sqt)	$y = 179.73 + 2.36x$	0.07	1.5	18.7
	Microbial biomass Carbon (C_{mic})	$y = 312.5 - 34.3x$	0.001	23.3	72.7
	Microbial biomass Nitrogen (N_{mic})	$y = 47.03 - 5.511x$	0.001	19.3	13.1
	pH	$y = 6.9731 - 0.0357x$	0.016	3.2	0.212

Table 4. 19 Relationship between soil organic carbon (soc) and some soil physical, hydrological and carbon parameters

x	**y**	**regression equation**	**F pr**	**%var accounted**	**SE**
	Physical properties				
Soil organic carbon	*Aggregate stability*	y = 33.2 + 17.27x	0.028	2.5	9.51
	Bulk density	y = 2.079 - 0.311x	0.01	3.8	0.15
	Total porosity	y = 21.7 +11.67x	0.01	3.7	5.47
	Hydrological				
Soil organic carbon	*Infiltration rate*	y = -0.1949 + 0.0977x	0.001	11.7	0.026
	Sorptivity	y = -6.37 + 3.132x	0.001	12.0	0.828
	Saturated hydraulic conductivity	y = -0.4099 + 0.2011x	0.001	16.1	0.045
	Carbon dynamics				
Soil organic carbon	*Carbon sequestration* (C Sqt)	y = 88.7 + 36.3x	0.018	3.1	18.5
	Microbial biomass Nitrogen (N_{mic})	y = -21.5 + 22.7x	0.059	1.7	14.5
	Microbial biomass Phosphorus (P_{mic})	y = 43.6 - 12.35x	0.054	1.8	7.75
	Microbial biomass C_{mic}/N_{mic}	y = 14.71 - 3.2x	0.01	3.8	1.49

Table 4. 20 Relationship between bulk density and some soil physical, hydrological and carbon parameters

x	y	regression equation	F pr	%var accounted	SE
	Physical properties				
Bulk density	*Aggregate stability*	y = 106.41-24.48x	0.001	13.6	8.95
	Aeration	y = 94.43-45.41x	0.001	51.6	6.49
	Total porosity	y = 99.775-37.57x	0.001	99.7	0.30
	Hydrological				
Bulk density	*Volumetric water content*	y = 5.35+7.84x	0.031	2.5	6.49
	infiltration rate	y = 0.1327-0.0747x	0.001	15.2	0.026
	Sorptivity	y = 3.523-1.951x	0.001	10.1	0.837
	Saturated hydraulic conductivity	y = 0.2025-0.1083x	0.001	10.0	0.047
	Carbon dynamics				
Bulk density	*Carbon sequestration* (C Sqt)	y = 14.32 + 116.68x	0.001	84.2	7.49
	Microbial biomass Carbon (C_{mic})	y = 21.9 + 140x	0.002	5.6	80.7
	Microbial Carbon Quotient (qC_{mic})	y = -0.001 + 0.676x	0.001	7.0	0.35

Table 4. 4 Relationship between aggregate stability and some soil physical, hydrological and microbial parameter

x	y	regression equation	F pr	%var accounted	SE
	Physical properties				
Aggregate stability	*Bulk density*	y = 1.7816-0.00579x	0.001	13.6	0.138
	Total porosity	y = 33.07 + 0.2142x	0.001	13.1	5.19
	Volumetric water content	y = 6.64 + 0.1279x	0.022	2.9	6.47
	Hydrological				
Aggregate stability	*Infiltration rate*	y = -0.0638 + 0.001298x	0.001	19.6	0.025
	Sorptivity	y = -1.583 + 0.03357x	0.001	12.8	0.824
	Saturated hydraulic conductivity	y = -0.1133 + 0.002305x	0.001	19.8	0.044
	Carbon dynamics				
Aggregate stability	*Microbial biomass Carbon* (C_{mic})	y = 455.8 - 3.332x	0.001	14.4	76.8
	Microbial biomass Nitrogen (N_{mic})	y = 54.7 - 0.325x	0.008	4.0	14.3
	Microbial biomass Phosphorus (P_{mic})	y = 46.12 - 0.425x	0.001	26.9	6.69
	pH	y = 7.723 - 0.01168x	0.001	26.8	0.184

Table 4. 22 Relationship between volumetric moisture content and some soil physical properties

x	**y**	**regression equation**	**F pr**	**% var accounted**	**SE**
Volumetric moisture content	*Gravimetric moisture content*	$y = 0.6 + 0.7008x$	0.001	91	1.45
	Degree of saturation	$y = -1.809 + 2.2088x$	0.001	92.5	4.14
	Aeration	$y = 51.1 - 1.1492x$	0.001	65.2	5.5

Table 4. 23Relationship between total nitrogen and microbial biomass nitrogen, microbial quotient nitrogen

x	**y**	**regression equation**	**F pr**	**%var accounted**	**SE**
Total Nitrogen	*Microbial biomass Nitrogen*	$y = 41.93 - 35.1x$	0.004	4.2	14.2
	Microbial Nitrogen Quotient (qN_{mic})	$y = 2.857 - 5.437x$	0.001	43.9	0.6

Table 4.24 Relationship between available phosphorus and microbial biomass phosphorus, microbial quotient phosphorus

x	**y**	**regression equation**	**F pr**	**%var accounted**	**SE**
Available Phosphorus	*Microbial biomass Phosphorus (qNmic)*	$y = -44.9 + 2.302x$	0.001	4.2	14.2
	Microbial Phosphorus Quotient (qP_{mic})	$y = -0.01239 + 0.000695x$	0.001	43.9	0.6

4.8 Principal component analysis (PCA) of the variables

4.8.1 PCA of soil physical and hydrological properties.

The Figure 4.29 illustrates the principal component analysis (PCA) of soil physical and hydrological properties which contains 150 individuals and 12 variables

The first two dimensions of analyses expressed 69.56 % of the total dataset inertia; that means that 69.56 % of the individuals (or variables) cloud total variability is explained by the plane.

The first dimension expressed 52.95 % of the data variability while the second expressed 16.61 %. Note that in such a case, the variability related to the other components might be no significant, despite a high percentage.

The observation thatthe first two dimensions of analysis express 69.56 % of the total dataset inertia suggests that only these axes are carrying a real information. As a consequence, the description will stand to these axes.

It was found that the most influential variables responsible for the 52.95 % variability observed in the first dimension were steady state infiltrability > cummulative infiltration amount > infiltration rate > saturated hydraulic conductivity while total porosity and bulk density were the main contributors of the 16.61 % variability observed in the second dimension (Figure 4.29). The analysis indicated a very close relationship between litter fall and aggregate stability. The results also showed that, steady state infiltrability, cummulative infiltration amount, infiltration rate and saturated hydraulic conductivity were grouped in the same quadrant and were strongly associated with each other.

The Wilks test p-value of soil physical and hydrological properties indicated that the best qualitative variable to illustrate the distance between individuals on this plane was land use, as illustrated in Figure 4.30 below.

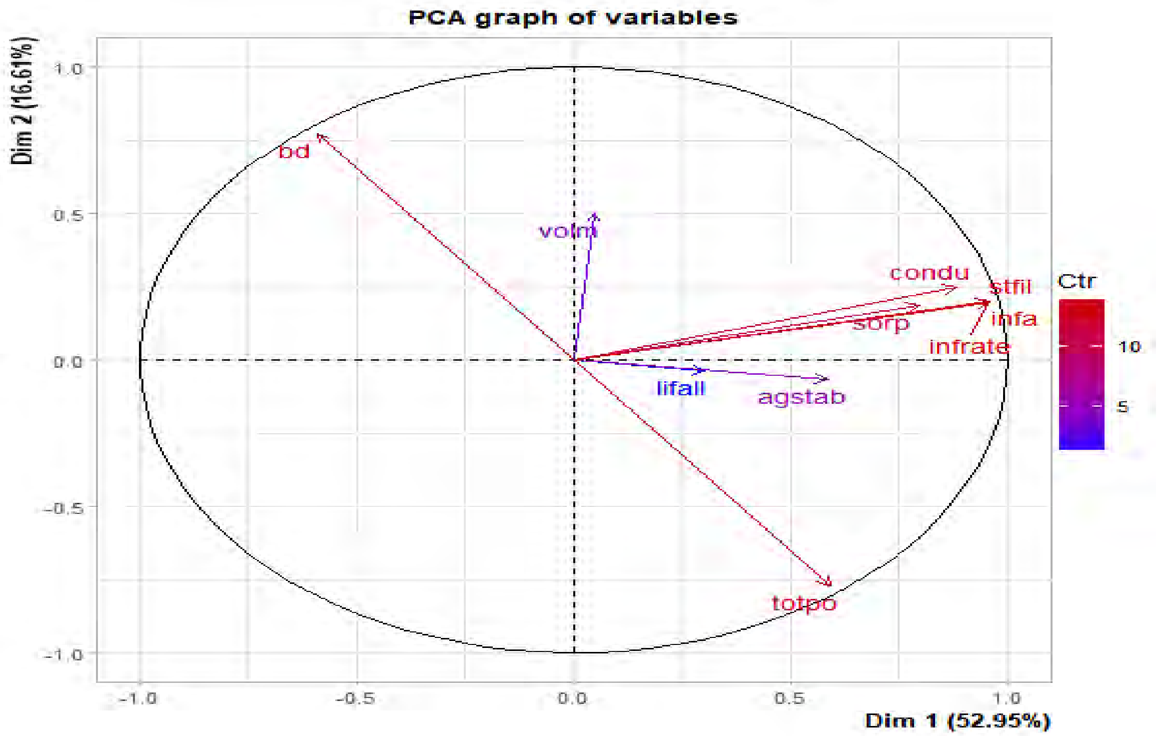

Figure 4. 4 Variable factor map (PCA) of soil physical and hydrological properties

bd = Bulk density; totpo = Total porosity; volm = Volumetric water content; agstab = Aggregate stability; lifall = Litter fall; infa = Infiltration amount; infrate = infiltration rate; sorp= Sorptivity; stfil = Steady state infiltrability; condu = Saturated hydraulic conductivity

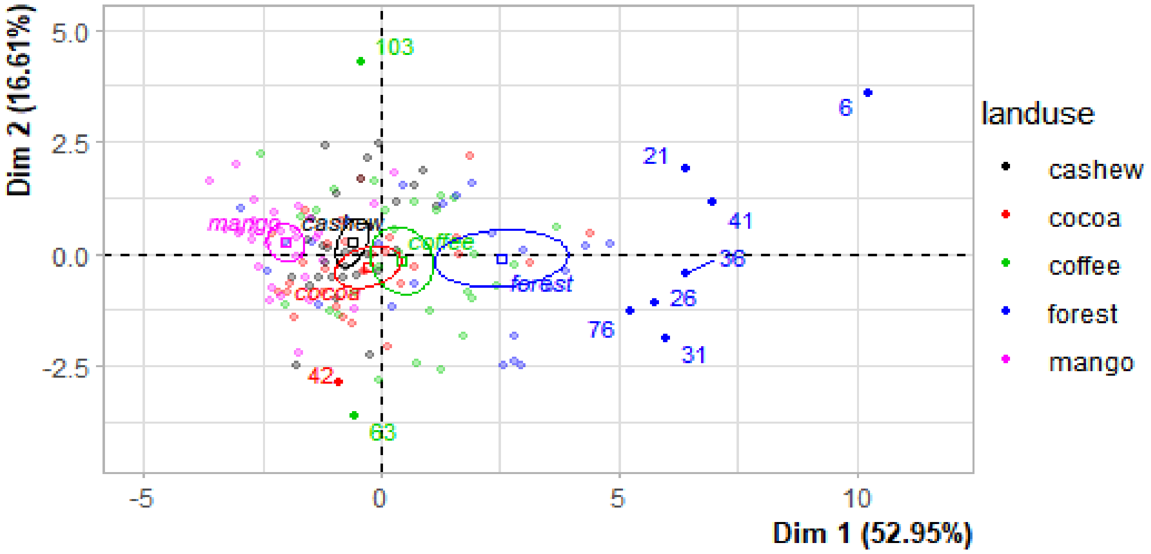

Figure 4. 5 Individual factor map (PCA) of soil physical and hydrological properties

The qualitative factor map of soil physical and hydrological properties indicated that cocoa plantation, coffee plantation and cashew plantation could be found around the factorial plane. Also, a stronger association was observed among cocoa plantation, DS2016, DS2017, MRS2016 and MRS2017, but were all far off mango plantation and forest, which were opposing each other (Figure 4.30).

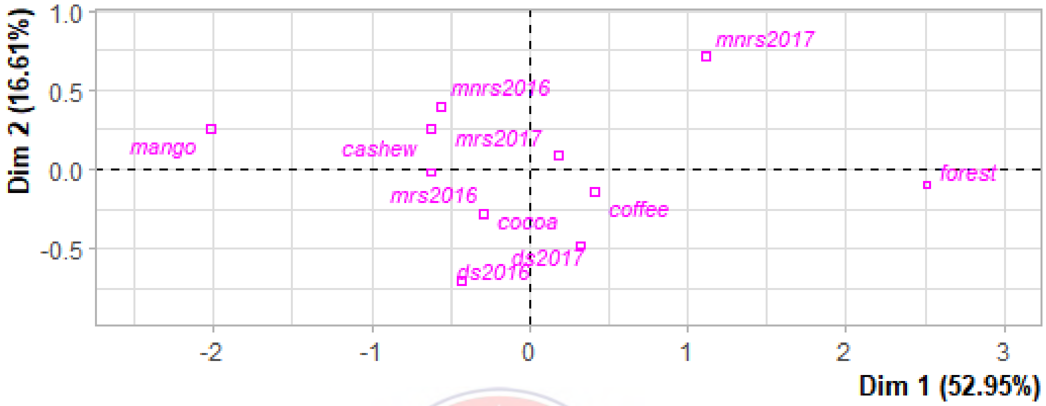

Figure 4. 6 Qualitative factor map (PCA) of soil physical and hydrological properties

4.8.2 PCA of soil physical and chemical properties

The principal component analysis (PCA) of soil physical and chemical properties is illustrated below in Figure 4.32.

The first two dimensions of analyse express 57.08 % of the total dataset inertia which means that 57.08 % of the individuals (or variables) cloud total variability is explained by the plane.

The first dimension expressed 39.50 % of the data variability, while the second, third, fourth, fifth, sixth, seventh, eighth, ninth and tenth dimensions expressed themselves 17.58 %, 14.03 %, 10.64 %, 9.11 %, 5.67 %, 3.44 %, 0.023 %, 0.008 % 0.000 respectively.

An estimation of the right number of axis to interpret suggests to restrict the analysis to the description of the first 3 axis. These axes present an amount of inertia greater than those obtained by the 0.95-quantile of random distributions (71.11 % against 40.96 %). This observation suggests that only these axes are carrying a real information and as a consequence, the description will stand to these axes.

litter fall, soil organic carbon, total nitogen and aggregate stability were grouped in the same quadrant and were strongly associated with each other. However, with the exception of aggregate stability that contributed to little variations observed in the first dimension. It was observed that total porosity negatively associated with bulk density while soil carbon stock was very close to the factorial plane. The most influential variables responsible for the 39.50% were total porosity > bulk density > aggregate stability in that order.

In the case of the PCA of soil physical and chemical properties, the Wilks test p-value indicated that the best qualitative variable to illustrate the distance between individuals on this plane was season, as illustrated in Figure 4.32 below.

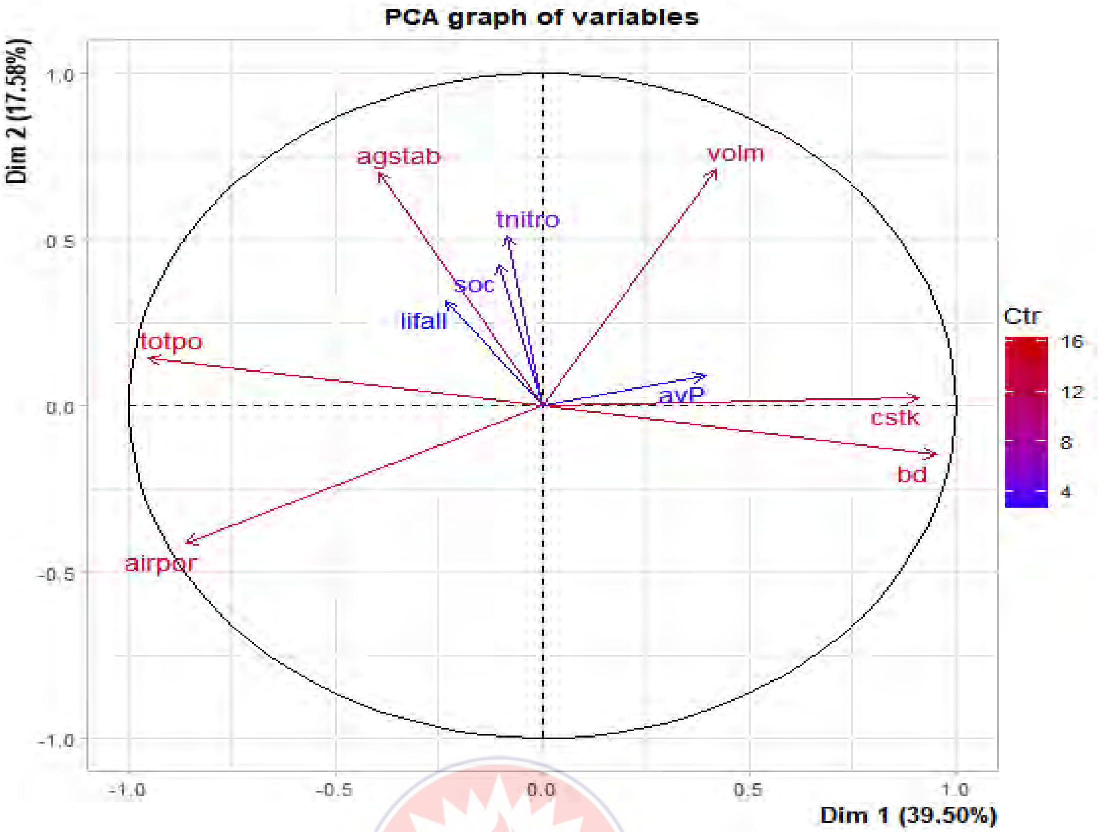

Figure 4. 31 Variables factor map (PCA) of soil physical and chemical properties

bd = Bulk density; totpo = Total porosity; volm = Volumetric water content; agstab = Aggregate stability; lifall = Litter fall; airport = Aeration porosity; soc =Soil organic carbon; tnitro = Total nitrogen; avP = Available Phosphorus; cstk =Carbon stock

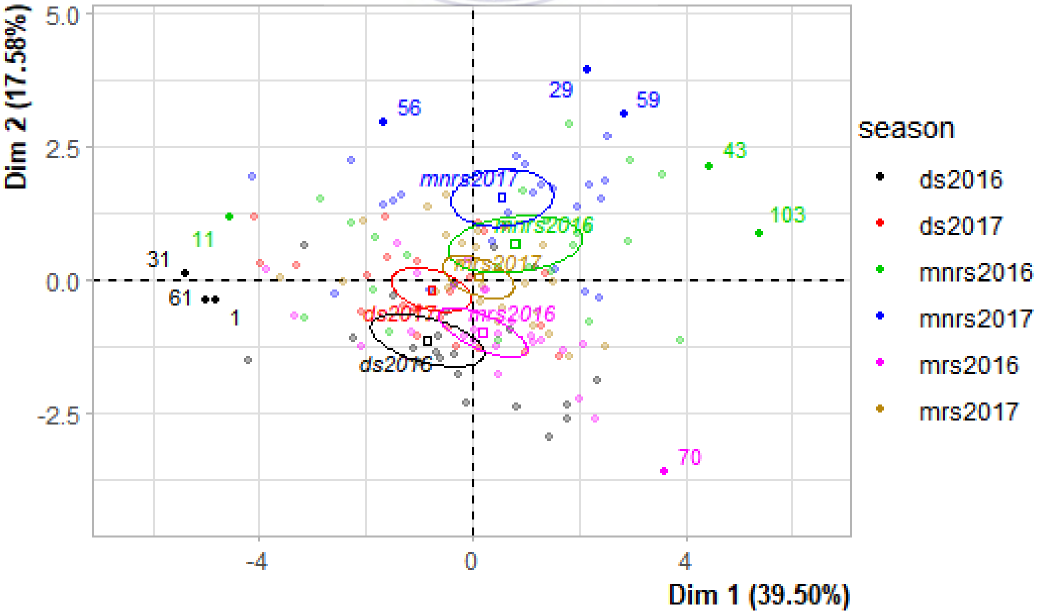

Figure 4. 32 Individual factor map (PCA) of soil physical and chemical properties

The forest and mango plantation were found far off each in opposite direction and they were both weakly associated with any other factor when the soil physical and chemical properties were qualitatively analyzed (Figure 4.33). The results also indicated that cocoa plantation was strongly associated with coffee plantation, DS2016, DS2017, MRS2016 and MRS2017 but not cashew plantation, MNRS2016 and MNRS2017.

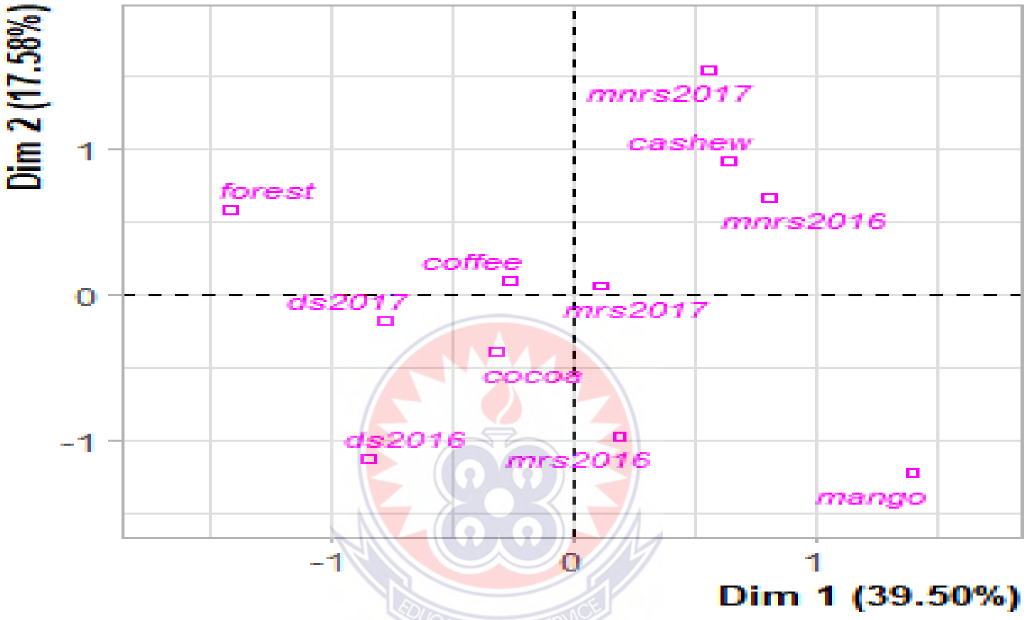

Figure 4. 33 Qualitative factor map (PCA) of soil physical and chemical properties

4.8.3 PCA of soil physical and microbial properties

Figure 4.34 below illustrates the variables factor map (PCA) of soil physical and microbial properties which contains 150 individuals and 12 variables.

The first two dimensions of the analysis expressed 69.05 % of the total dataset inertia which meant that, 69.05 % of the individuals (or variables) cloud total variability is explained by the plane.

The first dimension expressed 54.39 % of the data. In such a case, the variability related to the other components might be not significant, despite a high percentage.

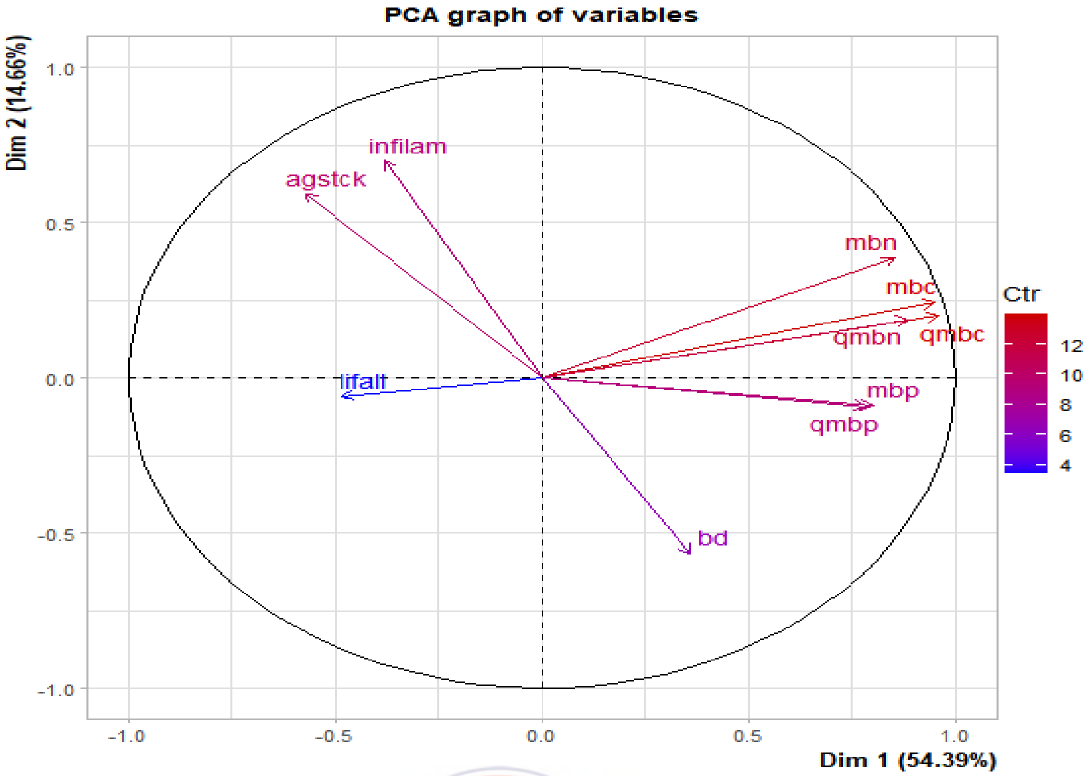

Figure 4. 34 Variables factor map (PCA) of soil physical and microbial properties

bd = Bulk density; infilam= Total porosity; agstab = Aggregate stability; lifall = Litter fall; mbc = Microbial biomass Carbon; mbn = Microbial biomass Nitrogen; mbp = Microbial biomass Phosphorus; qmbc= Microbial Carbon Quotient; qmbn = Microbial Nitrogen Quotient; qmbp= Microbial Phosphorus Quotient

An estimation of the right number of axis to interpret suggests to restrict the analysis to the description of the first 3 axis. These axes present an amount of inertia greater than those obtained by the 0.95-quantile of random distributions (81.83 % against 40.89 %). This observation suggests that only these axes are carrying a real information. As a consequence, the description will stand to these axes.

The most influential variables responsible for the 54.39 % were microbial biomass carbon > microbial carbon quotient > microbial biomass nitrogen > microbial nitrogen quotient > microbial biomass phosphorus > microbial phosphorus quotient in that order. From Figure 4.34, it was observed that bulk density had a negative relationship with infila were strongly associated with aggregate stability. Again, the results revealed that microbial biomass carbon, microbial carbon quotient, microbial biomass nitrogen and microbial nitrogen quotient were grouped in the same quadrant.

The Wilks test p-value of the individuals factor map (PCA) of soil physical and microbial properties indicated that the best qualitative variable to illustrate the distance between individuals on this plane was land use, as illustrated in Figure 4.36 below.

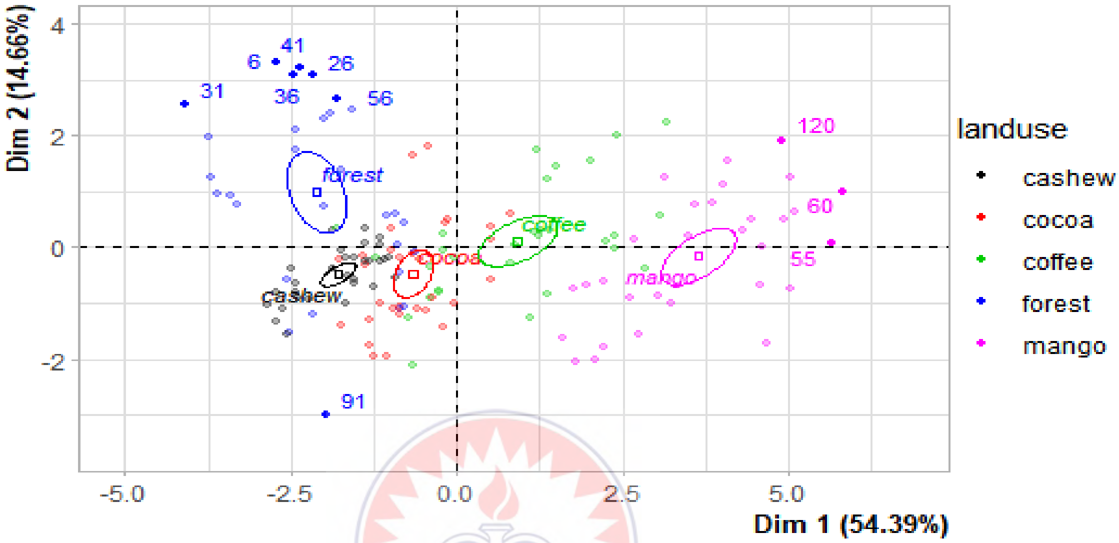

Figure 4.35 Individual factor map (PCA) of soil physical and microbial properties

The results of the qualitative factor map of soil physical and microbial properties indicated that cashew plantation and cocoa plantation were found in the same quadrant and had stronger association with the dry seasons (thus, DS2016 and DS2017).

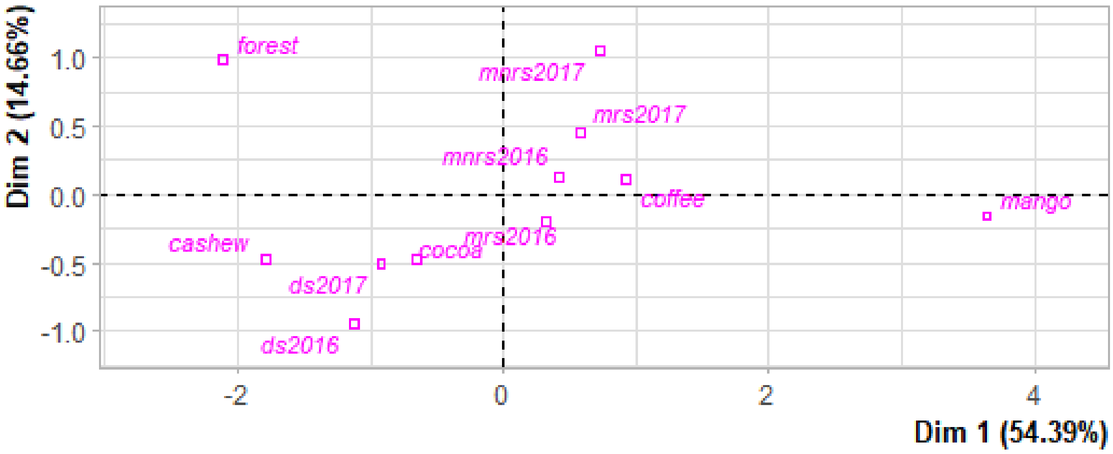

Figure 4. 7 Qualitative factor map (PCA) of soil physical and microbial properties

Mango plantation and coffee plantation could be found around the factorial plane with coffee plantation having a stronger association with MRS2016, MRS2017 and MNRS2017 (Figure 4.36).

4.8.4 PCA of soil chemical and microbial properties

The Figure 4.37 below illustrates the vvariables factor map (PCA) of soil physical and hydrological properties which contains 150 individuals and 12 variables

The first two dimensions of analyse express 66.96 % of the total dataset inertia; that means that 66.96 % of the individuals (or variables) cloud total variability is explained by the plane.

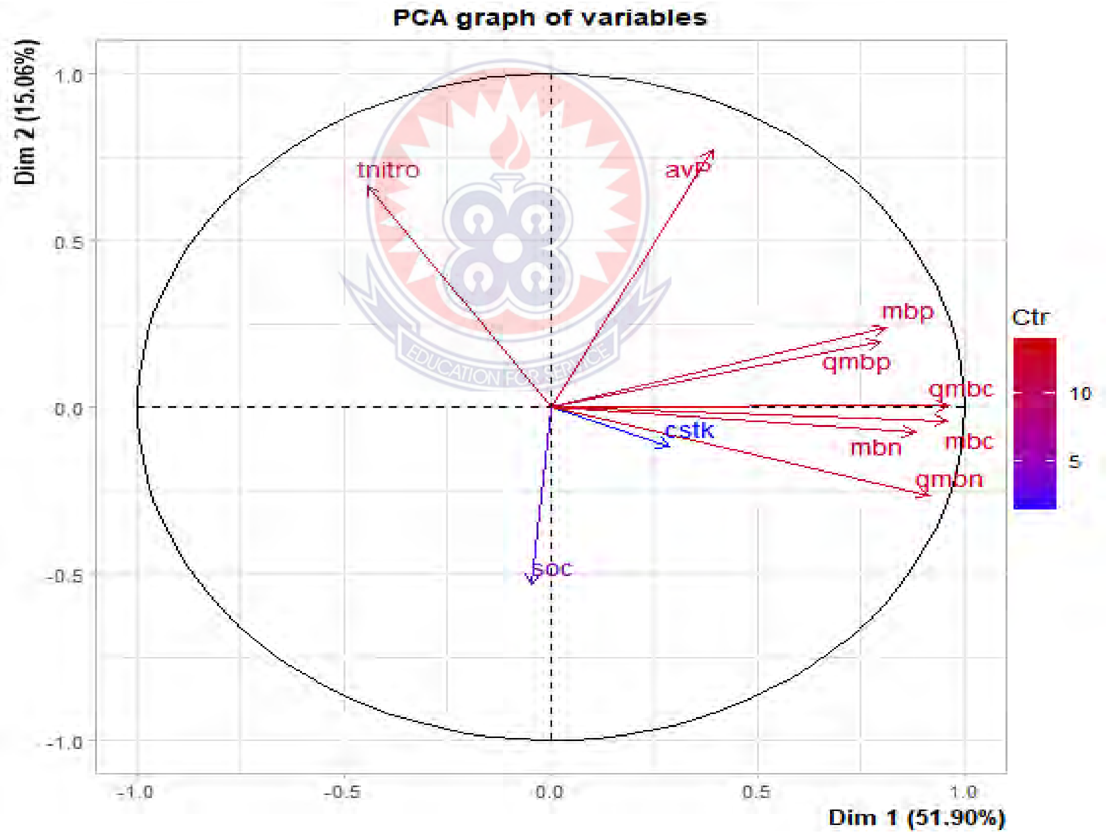

Figure 4. 37 Variables factor map (PCA) of soil chemical and microbial properties

soc = Soil organic carbon; tnitro = Total nitrogen; avP = Available Phosphorus; cstk =Carbon stock mbc = Microbial biomass Carbon; mbn = Microbial biomass Nitrogen; mbp = Microbial biomass Phosphorus; qmbc= Microbial Carbon Quotient; qmbn = Microbial Nitrogen Quotient; qmbp= Microbial Phosphorus Quotient

The first dimension expressed itself 51.90 % of the data variability while the second expressed itself 15.06 %. Note that in such a case, the variability related to the other components might be meaningless, despite of a high percentage.

The observation that first two dimensions of analysis expressed 66.96 % of the total dataset inertia suggests that only these axes are carrying a real information. As a consequence, the description will stand to these axes.

The variable factor map indicated that microbial biomass phosphorus, microbial phosphorus quotient and microbial carbon quotient were grouped in the same quadrant and were strongly associated with each other while microbial biomass carbon, microbial biomass nitrogen and microbial nitrogen quotient were also grouped in the same quadrant and also closely associated with each other. It was also observed that soil carbon stock was strongly associated with microbial nitrogen quotient. Figure 4.37 indicated the contribution of the variables r responsible for 51.90% variability observed in the first dimension with microbial carbon quotient > mnc > microbial nitrogen quotient > microbial biomass phosphorus > microbial phosphorus quotient.

The Wilks test p-value of the individuals factor map (PCA) of soil chemical and microbial properties indicated that the best qualitative variable to illustrate the distance between individuals on this plane was land use, as illustrated in Figure 4.38 below.

The qualitative factor map (Figure 4.39) indicated that forest and cocoa plantation were grouped within the same quadrant and were closely associated to each other. It also indicated that mango plantation was far away from any other land use.

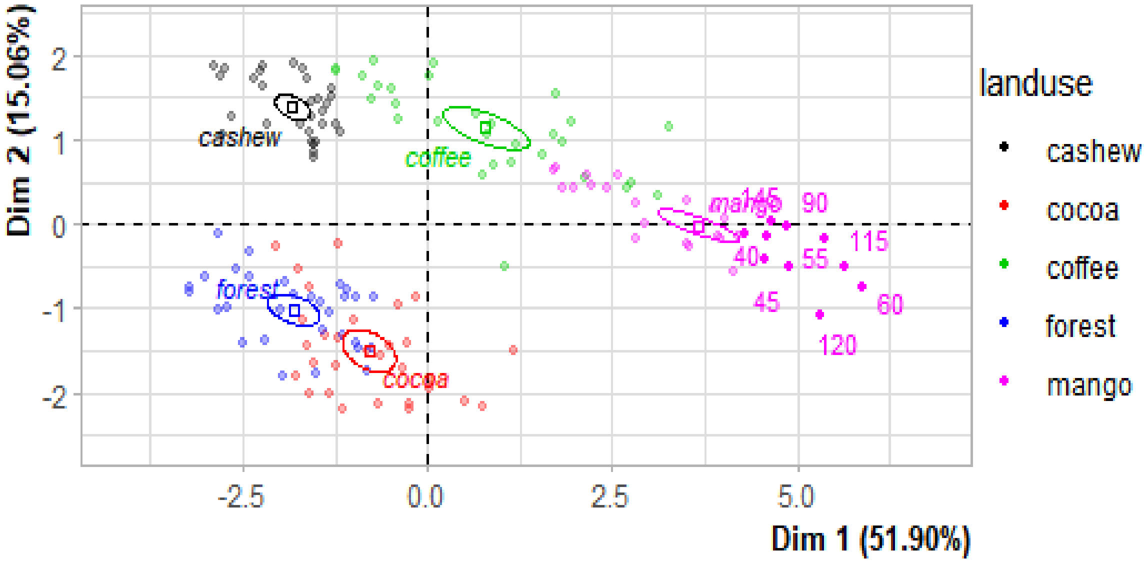

Figure 4. 38 Individual factor map (PCA) of soil chemical and microbial properties

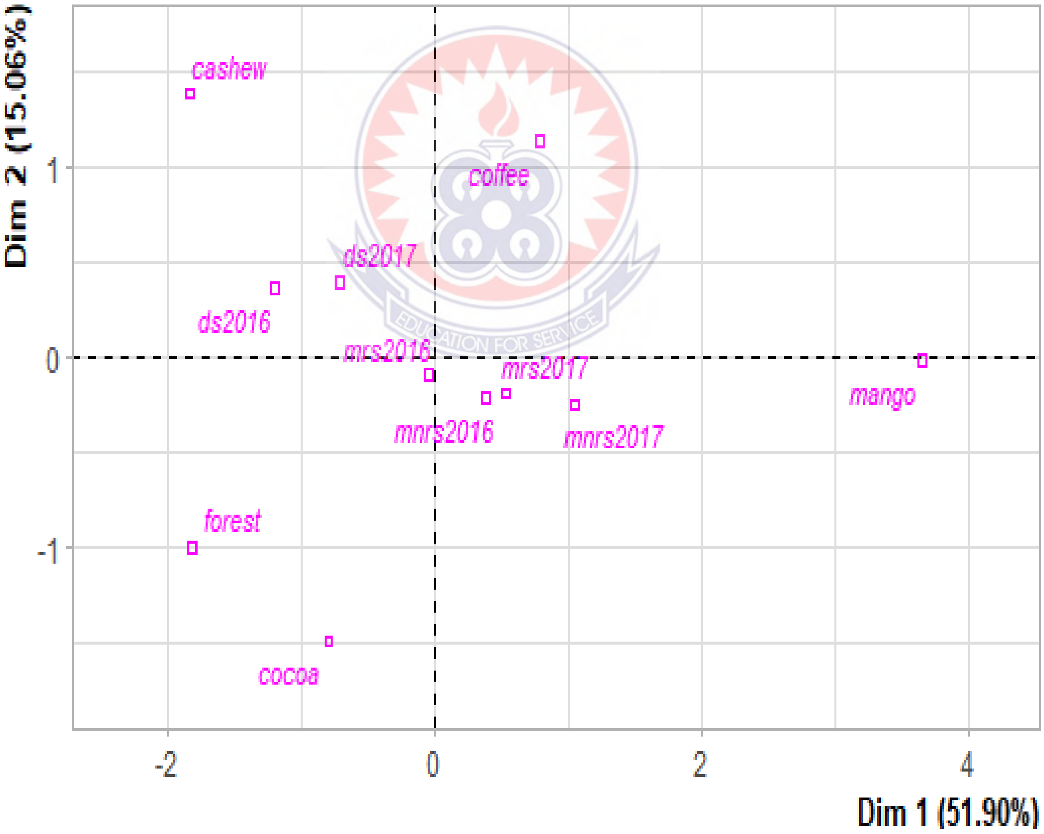

Figure 4.39 Qualitative factor map (PCA) of soil chemical and microbial properties

The analysis also revealed that the rain seasons whether major or minor were closely related to each other with a strong association.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Characterization of soil physical properties

5.1.1 Bulk density

Mango plantation had the highest bulk density as a result of its lowest rate of litter fall which corresponds to the lowest organic matter accumulation in the soil over time, and therefore could not have resulted in a reduction in the bulk density compared to the other land uses that had significantly higher quantities of litter fall. This confirms the assertion of Osei *et al.* (2018) who stated that addition of organic matter to the soil reduces soil bulk density. The observed highest bulk density of soils under the mango plantation could be attributed to its young age (13 years) of conversion from forest. Pinto *et al.* (2019) found that soil physical properties of forest are degraded during mechanical clearing and the bulk density turns to increase as a result of the mechanical land clearing of the forest. These changes in soil physical properties takes some time to return to its original state as in the forest. Also, according to Tuffour and Bonsu (2014), soil compaction occurs during forest stand clearing, which reduces the volume of macropores and therefore, increases soil bulk density while increasing the potential for surface ponding, runoff and/or erosion.

The results indicated no significant differences ($p < 0.05$) among the six seasons. This is because, the different rainfall amount, temperature, humidity and light intensity as they occurred in the various seasons did not influence the bulk density directly. Osei *et al.* (2017a) confirmed this observation that rainfall and temperature do not directly affect bulk density but can create a conducive environment for several soil fauna to flourish. Nevertheless, it was observed that bulk densities from similar seasons, for example the dry seasons (DS2016 and DS2017), major rainy seasons (MRS2016 and

MRS2017) and minor rainy seasons (MNRS2016 and MNRS2017) in different years did reduce.

5.1.2.1 Gravimetric soil moisture content

The gravimetric moisture content of soils under cashew plantation and cocoa plantations were significantly different ($p < 0.05$) from the forest stand, and mango and coffee plantations. However, cashew plantation was not significantly different from the cocoa plantation. There were also no significant differences among forest stand, mango and coffee plantations. The highest gravimetric moisture content recorded under the cashew plantation could be due to the high litter fall recorded (Table 4.4), which served as mulch. This affirms Kyere *et al.* (2018a), assertion that, mulch helps to conserve soil moisture by reducing the rate of soil water evaporation. Also, Buyer *et al.* (2017) reported that litter fall improves soil water holding capacity and reduces soil water losses by reducing evaporation.

The minor rainy seasons, i.e., MNRS2017and MNRS2016 recorded the highest gravimetric moisture content followed by the major rainy seasons (MRS2017 and MRS2016), while the dry seasons (DS2017 and DS2016) recorded the least seasonal gravimetric moisture content values. This observation was as a results of antecedent moisture content accumulated from the major rain season (Figure 4.2). Also, the dry seasons recorded low gravimetric moisture contents as results of no rainfall during the period coupled with high temperatures and low relative humidity leading to loss of soil moisture through evapo-transpiration. Osei *et al.* (2017) found that soil gravimetric moisture content did decrease significantly during the dry season when they compared *mucuna pruriens* as a soil amendment (live and insitu mulch)in both the rain and dry seasons.

5.1.2.2 Volumetric soil moisture content

A similar trend was observed in volumetric moisture content for the different land use as observed for gravimetric moisture content. Cashew plantation recorded the highest volumetric moisture content followed by cocoa plantation, while coffee plantation recorded the least value. However, mango plantation unlike other land uses moved from the fourth highest in gravimetric moisture content value to third highest in volumetric moisture content because volumetric moisture content is a function of gravimetric moisture content and bulk density. Therefore, the higher the bulk density of a soil the higher the likelihood of it recording high volumetric moisture content. This could be attributed to the mango plantation recording the highest bulk density (Table 4.2) although it had a relatively lower gravimetric moisture (Osei *et al.,* 2017). It was observed that similar seasons did record similar volumetric moisture content values. The minor rain seasons (MNRS2017 and MNRS2017) recorded the highest volumetric moisture content value in a respective year followed by the major rain seasons (MRS2017 and MRS2016) and the dry seasons (DS2017 and DS2016). Usually, more rainfall is expected in the major rain seasons than in minor rain seasons. However, there was more rain in the MNRS2016 than in the MRS2016 (Figure 4.2). The trend of dry, major rain and minor rain seasons in the year 2017 recording higher volumetric moisture content than dry, major rain and minor rain seasons in the year 2016 could be attributed to the year on accumulation of litter fall. Litter accumulation on the soil surface of the soil serves as mulch which helps to conserve soil moisture by reducing soil temperature and rate of evaporation of soil moisture from the surface of soil. This assertion is supported by Melenya *et al.* (2015) who reported that the cocoa plantation under deep litter recorded higher soil moisture content than cocoa plantation under shallow litter and under no weed control.

The observed difference among the seasonal volumetric moisture content is basically as a result of the fluctuations in rainfall quantities, temperature and humidity. Bolat *et al*. (2015) found that seasonal fluctuations in temperature, moisture and humidity does not only significantly influence soil moisture content but also soil microbial indexes.

5.1.3 Total porosity

The total soil porosity of forest stand, cocoa plantation and coffee plantation were not significantly different ($p < 0.05$) from each other, but were all significantly different ($p < 0.05$) from cashew and mango plantations. This observation can be attributed to the fact that total porosity is inversely proportional to bulk density (Figure 4.22.B). Therefore, as the forest stand recorded the least bulk density followed by cocoa plantation, coffee plantation, cashew plantation and mango plantation, it will in turn record the highest total porosity followed by cocoa plantation, coffee plantation, cashew plantation and mango plantation. High bulk density is an indicator of low soil porosity and high soil compaction. It may cause restrictions to root growth and poor movement of air and water through the soil (Osakwe and Igwe, 2013). It could also be that the decomposition of high litter fall recorded by forest stand, cocoa plantation and coffee plantation (Table 4.4) led to increase in soil organic matter which in turn contributed to the relatively high total porosity observed. This assertion is affirmed by Naik *et al.* (2016) who observed that soil organic matter increases land productivity through improved soil properties such as improved total porosity, decreased bulk density and moisture retention.

In addition, since soil physical properties are degraded during the conversion of forests into cash crop plantations, the lowest total porosity recorded by mango plantation could be attributed to the fact that it was the latest to be converted from the natural forest into a mango plantation and therefore might not have fully recovered from the degradation during the land preparation. Ghana Forest Plantation Strategy (GFPS) (2016) and Naaganoa *et al.* (2019) reported that the principal drivers of soil degradation in Ghana and across the world have been identified as agricultural expansion (e.g., permanent cultivation, free range cattle ranching, shifting cultivation/traditional slash and burn). Bonsu *et al.* (2011) reported that most of the soils in the tropics are not resilient, that is, their ability to return to their former condition after being subjected to stresses of land use is very weak.

5.1.4 Air filled porosity

Forest stand recorded the highest air-filled porosity while cashew plantation recorded the least among the land uses. This observation is related to the fact that, spaces (total porosity) within the soil are occupied by air and moisture. Therefore, if a soil recorded a high volumetric moisture content, that same soil will record a relatively low of air-filled porosity since the total soil porosity is the sum of the space occupied by volumetric moisture and air in the soil (Klute, 1986). This may explain why the forest stand recorded the highest air- filled porosity with a corresponding least volumetric moisture content, while cashew plantation recorded the least air- filled porosity with the corresponding highest volumetric moisture content (Table 4.2).

Significant differences were observed among the different seasons of dry, major and minor seasons, irrespective of the year (Figure 4.7). This is because similar seasons did record similar trends in rainfall, humidity, temperature wind speed and light intensity (Figure 4.2).

It was also observed that, air-filled porosity decreased from DS20016 > MNRS2016 > MRS2016 > DS20017 > MNRS2017 > MRS2017. This observation can be attributed to the fact that volumetric moisture content did increase along the same pattern with DS20016 < MNRS2016 < MRS2016 < DS20017 > MNRS2017 > MRS2017.

There was interaction between the land use and seasonal values of air-filled porosity. With coffee×DS2016 recording the highest air-filled porosity followed by Forest×DS2016 and Forest×DS2017, while Cashew×MNRS2016 recorded the least value This means that air-filled porosity recorded by the different land uses is influenced significantly by the different seasons.

5.1.5 Aggregate stability

The forest stand recorded the highest aggregate stability while mango plantation recorded the least value as a result high litter fall in the forest stand and least litter fall in the mango plantation (Table 4.4). Aggregate stability is the measure of the ability of a soil to resist destruction or breakage by rain drops. Therefore, the higher litter fall recorded by forest stand was able to protect (mulch) the soil surface more effectively and hence prevented or reduced the rate of disintegration of soil particles by rain drops.

In addition, the least aggregate stability recorded under the mango plantation could be attributed to the lowest soil organic carbon content (Table 4.4). Soil organic carbon content is noted to aid in the binding of soil particles together and reduce its rate of disintegration by rain drops. This assertion is supported by Tuffour and Bonsu (2014), who reported a positive linear relation between aggregate stability and soil organic carbon (R^2 = 0.911) and stated that the high coefficient of determination indicated that 91.1% of the variation in aggregate stability may be ascribed to soil organic carbon. This high positive correlation between soil organic carbon and aggregate stability showed that soil organic carbon acted as a cementing agent linked with stabilizing micro-aggregates into macro-aggregates (Kemper and Rosenau, 1984).

There were significant differences ($p < 0.05$) among the seasonal values of soil aggregate stability. There was a general increase in soil aggregate stability from DS2016 to MNRS2017. The trend of general increase in aggregate stability observed can be associated with the same trend observed in seasonal soil organic carbon content observed in Table 4.4. This is because soil organic matter serves as a binding agent that cements soil aggregates hence reducing the rate of destruction by rain drops (Osei *et al.,* 2017). This trend could have also been as a result of the continuous accumulation of litter on the soil surface season on season. These litter serve as mulch which in turn protect the surface of the soil surface from destruction by raindrops. This assertion is confirmed by Kyere *et al.* (2018) who reported that the thicker the mulching material the higher its ability to protect soil aggregates from destruction.

5.2 Influence of land use and season on soil hydraulic and hydrological properties.

5.2.1 Cumulative infiltration amount

Forest stand recorded the highest cumulative infiltration amount, while mango plantation recorded the least. Apart from cocoa and cashew plantations all the other land uses were significantly different ($p < 0.05$) from each other. Forest stand recorded the highest cumulative infiltration amount probably because its soils are in their natural state and has never undergone degeneration as a results of land use change which often cause soil compaction and reduce its porosity and organic carbon. Hence has less spaces for water to enter the soil through the surface. This assertion was confirmed by the mango plantation which recorded the least cumulative infiltration amount since it was the latest land use change. Pinto *et al.* (2019) found that physical properties of soil under forest were degraded during mechanical clearing and the bulk density turns to increase while total porosity decreases as a results of land preparation for the new land uses.

The forest stand recorded the least bulk density and the highest total porosity, which meant its soil was less compact and more spaces for water infiltration. Unlike the forest stand, mango plantation recorded the highest bulk density and the least total porosity, hence it had less spaces for water iinfiltration. This is supported by Horel *et al.* (2015) who reported that the intensification of soil disturbance through land use change, in general, leads to an increase in soil bulk density, decrease in total porosity and a decrease in soil water retention as well.

The high cumulative infiltration amount by forest stand, coffee and cocoa plantations were also basically as a result of their high sorptivity (which controls the initial stage of infiltration in this case, 5 min) Table 4.3 and the steady state infiltrability which describes the infiltration rate at full saturation of the soil (Tetteh, 2017).

This could have been as a result of the completely different temperature, humidity and rainfall values recorded during the different seasons. Also, it could be as a result of climate change as from Figure 4.2, MRS2016 which was supposed to be a major rain season and therefore expected to record higher seasonal rainfall values rather recorded a lower seasonal rainfall value than MNRS2016 which is a minor rain season. Attakorah (2020) reported a similar situation in 2016 where a lower seasonal rainfall during the major rain season than the minor rain season was recorded at both experimental sites at the Crop Research Institute, Kumasi and UEW Mampong campus respectively, in the year 2016.

5.2.2 Infiltration rate

Soil under mango plantation recorded the least infiltration rate while soils under forest stand recorded the highest value of infiltration rate. This trend was similar to the observation recorded in the case of the cumulative infiltration amount. Similar to cumulative infiltration amount where there was no significant difference between cocoa plantation and cashew plantation, but different in all other land uses, infiltration rates were significantly different from each other except cocoa and cashew plantations which were similar. The mango plantation and forest stand could have recorded the lowest and highest infiltration rates respectively because mango plantation recorded the least sorptivity value, while forest stand recorded the highest sorptivity value. According to Philip (1957), sorptivity is an important parameter in the description of both cumulative and instantaneous infiltration. It also controls the initial state of infiltration. Hence, higher sorptivity leads to higher infiltration rate.

Similar to seasonal cumulative infiltration amount, seasonal infiltration rate was not significantly different from each other.

5.2.3 Sorptivity

There were significant differences in sorptivity ($p < 0.05$) among the land uses. Soils under mango plantation recorded the least sorptivity value while the forest stand recorded the highest sorptivity value. While sorptivity under cashew and mango plantations were not significantly ($p < 0.05$) different from each other, there were significant differences among forest stand, cocoa and coffee plantations.

This observation could be attributed to the forest stand having recorded the least bulk density coupled with the highest total porosity hence it was less compacted and had more soil pores for iinfiltration of water. Conversely, mango plantation might have recorded the least sorptivity because it recorded the highest bulk density and the lowest total porosity among the different land uses. Hence it had less pores for the absorption of water and relatively low infiltration amount since the amount of water that enters the soil from its surface also influences the ability of the soil to absorb water (Table 4.3). Osei *et al.* (2017) in their work on “response of hydro-physical properties of a Chromic Luvisol in Ghana to different methods of application of Mucuna pruriens as a soil amendment” found that total porosity positively correlated with sorptivity.

Generally, there was a gradual 16%-84% increase in sorptivity from DS2016 to the MNRS2017 (Table 4.3). This gradual season increases could be attributed to the accumulation and decomposition of litter that led to decrease in the bulk density and increase total porosity hence leading to the seasonal increase in sorptivity of the soil. These finding are in agreement with Babur (2019) who reported that decomposition of accumulated organic matter coupled with fluctuations in temperature and rainfall lead to increase in soil microbial activities which in turn decrease soil bulk density and increase soil porosity.

5.2.4 Steady state infiltrability

This is a point in infiltration rate where when any extra water that is added to the soil will lead to flooding or it is the point on an infiltration rate graph where the infiltration rate graph line is parallel to the x axis. Steady state infiltrability also describes the infiltration rate at full saturation of the soil.

Forest stand recorded the highest steady state infiltrability, followed by coffee plantation, cocoa plantation and cashew plantation, while mango plantation recorded the least state infiltrability. Forest stand and coffee plantation steady state infiltrability significantly different ($p < 0.05$) from all the other treatments. The observation could be attributed to the time frame of land use change. The forest stand had never undergone a land use change while mango plantation was the latest (13 years) to undergo land use change and probably have not fully recovered from the degradation caused during the land use change. Pinto *et al.* (2019), suggested that deforestation of the native forest can reduce the steady state infiltrability, thus decreasing soil water infiltration, groundwater recharge and water storage capacity, a behaviour which can increase the surface runoff and soil erosion.

In addition, mango plantation recording the lowest steady infiltrability can be associated with its relatively low porosity as reported by Pinto *et al.* (2017). They observed, an intrinsic relationship between soil drainable porosity, steady state infiltrability and land-use.

No significant differences were observed among the seasonal steady state infiltabity due to the high spatial variability of steady state infiltrability. The high spatial variability of steady state infiltrability occured due to different extrinsic and intrinsic factors, including geomorphic surface, weather, land-use and management, soil structure, soil granulometric distribution and bulk density (Zimmermann *et al*., 2013). Wang *et al*. (2018) also reported that, high spatial variability of steady state infiltrability makes it difficult to predict and characterize steady state infiltrability.

5.2.5 Saturated hydraulic conductivity

Analysis of soil saturated hydraulic conductivity showed significant differences in the different land uses. Forest stand recorded the highest value, followed by coffee plantation, cocoa plantation, cashew plantation and mango plantation. The high sand contents in forest stand and coffee plantation soils coupled with high porosity and low bulk density within the 0 – 15 cm depth might have improved the soil macro porosity (Silva *et al*., 2011) which greatly influenced soil permeability. Thus, the predominance of macropores in relation to the micropores are a reflection of the observed high hydraulic conductivity of forest stand and coffee plantation. These observations support earlier assertions by Pattanayak and Mercer (1996) on the effects of agroforestry on soil, which include reduction of runoff and/or erosion, basically through the improvement of soil physical properties such as structure, porosity, and moisture retention as a result of extensive root system and the canopy cover (Tetteh, 2017).

Significant differences were observed among seasonal saturated hydraulic conductivity. There was a general increase from DS2016 to MNRS2017. This observation can be attributed to the general increase in seasonal values of sorptivity coupled with the high porosity recorded as a result of the continuous decomposition of litter which led to the reduction of bulk density and increase in total soil porosity. Structural changes in soil properties changes such as soil bulk density, total porosity, macro porosity, pore-size distribution influences the soil saturated hydraulic conductivity (Horel *et al.,* 2015).

5.3 Influence of land use and season on litter fall and carbon accumulation

5.3.1 Litter fall

Litter fall is a major process by which carbon and nutrients are transferred from vegetation to soil (Dawoe, 2009). There were significant differences among the litter fall under different land use. Litter fall from the forest stand was the highest, which was not significantly different from that of cocoa plantation and cashew plantation, but significantly different from coffee plantation and mango plantation which recorded the lowest litter fall. These differences observed might have been due to the different stand-age of the different land use, stand density, and the morphology of the different land uses (Yang *et al*., 2003: Dawoe, 2009).

Significant differences were observed among the litter fall of the different seasons. DS2017 recorded the highest litter fall quantities, while MRS2016 recorded the lowest litter fall. This is consistent with Lawrence and Foster (2002) who reported that most litter fall studies in tropical forests have demonstrated a strong seasonality of leaf litter fall, with the dry season being the peak of litter fall. Again, the increase in litter fall during the dry seasons may be attributed to the physiological response of the different land uses to drought and reduced humidity in the seasons with less rainfall. These factors together with lower night temperatures that prevail during the dry seasons are known to stimulate abscisic acid synthesis in plant foliage, which, in turn, stimulates leaf senescence (Yang *et al*., 2003).

In the study, it was observed that seasonal litter fall of similar seasons thus Dry seasons (DS2016 and DS2017), Major rain season (MRS2016 and MRS2017) and Minor rain seasons (MNRS2016 and MNRS2017) were not significantly different from each other. This trend may be as a result of the fact that litter fall may be affected by physical factors such as the mechanic action of wind and rain or physiological responses of the plants to environment changes (Babur, 2018). Since, similar rainfall, humidity, temperature and light intensity was observed in the dry seasons, major rain seasons and minor rain seasons hence the similarity in the seasonal litter fall observed in similar seasons.

5.3.2 Soil organic carbon

Significant differences in soil organic carbon were observed among the different land uses. Forest stand recorded the highest soil organic carbon content followed by cocoa, coffee and mango plantations, while cashew plantation recorded the least soil organic carbon content. This is because the forest stands were in their natural state and had not suffered the soil degradation which usually occurs during land use change and therefore, its soil organic carbon is more stable than other land uses. Woloszczyka *et al.* (2020) affirmed that forest soil organic carbon appears almost undegraded, and thus is most stable in the long term when compared to other land uses. Similarly, James and Harrison (2016) reported that anthropogenic disturbance, related to both conversion of forests to other land uses, and modifications of forests influence forest soil organic carbon.

Soil organic carbon under the coffee plantation was significantly different from mango and cashew plantations because its leaves had relatively lower C: N ratio than that of mango and cashew plantations. Triadiati, *et al*. (2011), reported that, lower SOC in the old cocoa plantation might be due to the relatively slow rate of cocoa plantation leaf litter materials decomposition because of its relatively higher C: N ratio than the natural forest.

DS2016 recorded the least soil organic carbon content, while MNRS2017 recorded the highest soil organic carbon content. A gradual increase of seasonal soil organic carbon content was observed from the first season to the last season of the study (2.234 % - 2.3892 % that is about 6.9 % increment). This is because of the continuous decomposition of accumulated organic matter (Daouda *et al.,* 2017; Kyere *et al.*, 2018).

It was also observed that there was a slight decrease in soil organic matter in the dry season which could be as a result of the inadequate moisture availability coupled with high temperatures observed during the dry season, hence negatively affecting soil microorganism that are responsible for breaking down these organic matter to release the soil organic carbon .This is consistent with Olojugba (2018) who reported that low rains caused low percentage of soil organic carbon in the dry season of the year (November - February). The decrease in soil organic carbon in the dry season might be due to little or absence of soil microorganisms that are responsible for the decomposition. Batjes (2011) also reported that biological processes such as decomposition is enhanced by increasing temperatures in soils with sufficient amount of moisture, and oxygen. Thus, the fluctuation of rainfall, temperature and humidity might be responsible for the lower SOC observed in the dry seasons.

5.3.3 Soil carbon stocks

There were no significant differences among the soil carbon stocks of the different land uses. This is consistent with Dawoe (2009), who reported that soil carbon stock changes in the natural forest were not significantly different from cocoa plantation. Although, there were no significant difference among the different land uses in this study, mango plantation recorded the highest soil carbon stocks, followed by cashew plantation, cocoa plantation, coffee plantation and the forest. Mango plantation, cashew plantation, cocoa plantation and coffee plantation stored 6.8 %, 3.0 %, 2.9 % and 2.5 % more soil carbon than the forest. This confirms the assertion that tree plantations turn to mimic natural forest with time. Since, mango plantation which was the latest to have been converted from natural forest stand (13 years ago) as at the time of the experiment, it is possible that all the other land uses might have recovered from the land degradation due to disturbance from the land use changes hence recording similar soil carbon stocks as the forest. Kone and Yao (2021), reported that soil carbon stocks of tree plantations, teak (*Tectona grandis*), cocoa plantation (*Theobroma cacoa*) and a mixture of four different species in their study were not significantly different from the natural forest. They also reported that, trees do not only mimic the natural forest in soil carbon stocks, but also in soil microbial activities and some soil physical properties and as such tree plantations can be used to develop climate smart timber system in West and central Africa.

Since, Soil carbon stock is a function of ssoil organic carbon, bulk density and soil depth, the non-significant differences among the different land uses could be attributed to the fact that, although, forest stand recorded the highest soil organic carbon it also recorded the lowest bulk density which led to it recording a similar soil carbon stocks with other land uses like mango plantation and cashew plantation which recorded the least soil organic carbon but the highest bulk density.

MRS2017 (48.15 Mg C/ha) recorded the highest seasonal soil carbon stocks value and DS2016 (44.96 Mg C/ha) recorded the seasonal least soil carbon stocks. Although, there were no significant differences ($P < 0.05$) among the seasonal soil carbon stocks, an increase of about 7.1 % was observed from DS2016 and MNR2017. This shows that with time the amount of storage will increase. This confirms Woloszczyka *et al.* (2020), assertion that it takes relatively a long time for carbon to be stable and stored in the soil. Also, Nair and Nair (2014), reported that it takes time to increase soil carbon stocks.

5.3.4 Carbon Sequestration

There were no significant differences among the Carbon sequestration values of the different land uses. However, it was observed that, cocoa plantation, coffee plantation, cashew plantation and mango plantation sequestered 2.9 %, 2.6 %, 3 % and 6.7 % more carbon respectively than the forest. The non-significant difference observed among the different land uses could be as a result of the mimicking nature of the tree crops thus cocoa plantation, coffee plantation cashew plantation and mango plantation as reported by Young (2017), that tree crops are able to mimic the natural forest by providing similar environmental condition of a natural forest. Kyrlund (1990), as reported in Dawoe (2009), found that, the amount of biomass accumulated through forest tree-growth gradually decreases as forest age increases; it follows that the carbon sequestration potential of forests also decreases over time. Nonetheless, Kyrlund (1990), reports that undisturbed tropical moist forests show net growth, and thus net carbon sequestration, for 100 years after establishment. Therefore, although other forest-based systems, such as young plantations, can sequester carbon at a higher rate than mature forests, primary forests conserve much more carbon per hectare, thereby conserving the terrestrial carbon pool and preventing carbon release into the atmosphere (Kyrlund, 1990). Again, Durot, (2013), reported that tree-based systems such as cashew plantation, cocoa plantation and agroforestry, sequestered carbon more than double what was observed in the traditional fallows.

Although, there were no significant differences among the seasonal carbon sequestration values, a 6.8 % increase in amount of carbon sequestered was observed from DS2016 and MNR2017 which is an indication that with time there could be significant differences. Nair and Nair (2014), said that increase in soil stocks over time forms carbon sequestration as carbon additions and storage in the soil through litter fall and external additions are subject to rapid decomposition and release of CO_2, with only a small percentage of C becoming stable C in ‘long-lived’ pools.

There was interaction between the land use and season on values of soil carbon sequestration indicating that the different land use soil carbon sequestration values are significantly influenced by seasonal variabilities.

5.4 Effect of land use and season on some soil chemical properties

5.4.1 Effect of land use and season on total nitrogen

According to Mhawish, (2015), when the forest is converted for agricultural use, nitrogen becomes the most important element in the ecosystem. In this study, it was observed that, soil total nitrogen of the different land uses was moderate to high, with cashew plantation recording the highest soil total nitrogen, followed by coffee plantation, forest, and cocoa plantation while mango plantation recorded the lowest value of soil total nitrogen. Except, cashew plantation and coffee plantation which were not significantly different from each other, all other land uses were significantly different from each other. This trend could have been as a result of the low C: N ratio of the leaves and the relatively high nitrogen content of coffee plantation and cashew plantation hence their leaves decomposed faster and released nitrogen into the soil. Similary, mango plantation recorded the least total nitrogen probably because its leaves had the highest C: N ratio and hence the release of nitrogen into the soil was relatively slower.

Mango plantation could have also recorded the lowest total nitrogen because it recorded the lowest litter fall (Table 4.4) and therefore lower nitrogen was added to the soil after mineralization. This is consistent with Djagbletey (2017), who reported that nitrogen and phosphorus content in the soil correlated positively with the amount of litter sock.

Mango plantation been the latest to have been converted from the forest stand recorded the lowest nitrogen because probably it had not fully recovered from the soil degradation during the land use change. Muñoz-Rojas *et al.* (2015), said that land-use changes from forest cover to cultivated land may reduce input or organic residues that lead to a decline in soil fertility. Alam *et al.* (2017), observed significant reductions in NO_3 in soil solutions and soil N following forest clearing.

Significant differences ($p < 0.05$) were observed among the soil total nitrogen values of the different seasons. MNRS2017 recorded the highest soil total nitrogen while DS2016 recorded the lowest. It was observed that in the rain seasons (MRS2016, MRS2017, MNRS2016 and MNRS2017) soil total nitrogen increased while it decreased significant in the dry seasons (DS2016 and DS2017). This could be as a result of increased activity of nitrogen fixing microbes during the rain seasons, low rainfall which reduced mineralization as well as the distribution of soil organic matter in the area might have accounted for low total nitrogen distribution during the dry season and at the beginning of rains (NurQursyna *et al.,* 2013). However, the moderate total nitrogen recorded during the peak of rainfall (June/July and September) might be interlinked with the high rate of mineralization due to high rainfall, (Olujugba *et al.,* 2018).

An interaction was observed between land use and seasonal soil total nitrogen values. This indicates that land use nitrogen values are significantly influences by seasonal varitions

5.4.2 Effect of land use and season on available phosphorus

Phosphorus is considered a limiting nutrient for biological activities in forest ecosystems (Mhawish, 2015). In this study, soil available phosphorus varied significantly ($p < 0.05$) among the land uses and ranged from 27.038 mg/kg to 24.663 mg/kg with Cashew plantation and cocoa plantation recording the highest and lowest soil available phosphorus values respectively. According to SRI (2013) the soil available phosphorus recorded in this study is high (Appendix A). Cashew plantation recorded the highest soil available phosphorus value probably because it recorded the highest litter and therefore more phosphorus might have been added during the decomposition and mineralisation of these litter. This is consistent with Dawoe (2009) work, "conversion of natural forest to cocoa plantation agroforest in lowland humid Ghana: impact on plant biomass production, organic carbon and nutrient dynamics" where he reported that organic matter normally accounts for up to 50% of the total phosphorus in the surface horizons of tropical soils and may represent 60-80% of the total soil phosphorus in highly weathered Oxisols, Ultisols, and Alfisols. Also, Ahenkorah *et al*. (1987), reported that, organic phosphorus circulates rapidly between plant and soil via the litter, and its release through decomposition can be an important regulator of productivity.

Contrary to McGrath *et al*. (2001), Dawoe (2009) and Djagbletey (2017), all other land uses with the exception of cocoa plantation recorded higher available phosphorus values than the intact forest. This can be attributed to the fact that when tree crops are managed well, they could mimic the natural forest (Kone and Yao, 2021).

For seasonal soil available phosphorus values, it was observed that different seasons were significantly ($p < 0.05$) different from each other. There was a general increase in available phosphorus from DS2016 to MNRS2017. This gradual increase (0.47 %-3.8 %) can be attributed to the season on season addition of litter coupled with the conducive environment created during the rain seasons for the decomposition and release of nutrients into the soil (Mayer *et al.,* 2020).

There was an interaction between land use and season on soil available phosphorus values

5.4.3 Effect of land use and season on basic exchangeable cations (K^+, Ca^{2+} and Mg^{2+}) contents

Measured individual K^+, Ca^{2+} and Mg^{2+} within the different land uses were significantly ($p < 0.05$) different when analysed. Coffee plantation soil recorded the highest (0.415 $cmol_c/kg$) exchangeable K while cashew plantation (0.116 $cmol_c/kg$) recorded the least exchangeable K. It was observed that coffee plantation> forest >cocoa plantation >mango> cashew plantation. When the natural forest is used as a base it was observed that conversion of the forest stand led to a 46 % increase of K^+ in coffee plantation while a decrease of 9.2 %, 59 % and 53 % were observed in cocoa plantation, cashew plantation and mango plantation respectively. This is consistent with Awotoye *et al*. (2013), who reported that the conversion of natural forest to other agricultural uses led to a decrease in soil fertility.

A similar trend was observed in exchangeable magnesium where coffee plantation recorded the highest Mg^{2+} (2.194 $cmol_c$/kg) while cashew plantation recorded the least and Mg^{2+} (0.006 $cmol_c$/kg). Again, it was observed in this study that conversion of forest stand to agricultural uses led to a 1.6 % increase of Mg^{2+} in coffee plantation while a 98 %, 99.8 % and 51 % decrease were observed in cocoa plantation, cashew plantation and mango plantation respectively.

Soil exchangeable calcium of the different land uses were significantly different when analysed. Cocoa plantation recorded the highest Ca^{2+} followed by forest, mango plantation and coffee plantation while cashew plantation recorded the least. The study revealed that when the forest stand was converted to agricultural use it led to a 5.2 % increase in Ca^{2+} of soils under cocoa plantation while it led to a 40.27 %, 84.7 % and 38.2 % decrease in coffee plantation, cashew plantation and mango plantation Ca^{2+} values respectively. This finding is in conformity with Nave *et al.* (2019) who reported that the impact of converting primary forests to an agricultural land use leads to degradation of both physical and chemical properties of the soil which includes a reduction in exchangeable cations.

There was no significant ($p < 0.05$) difference among the seasons neither was there an interaction between the land use and season for all the exchangeable bases.

5.4.4 Effect of land use and season on soil pH

According to Tuffour *et al*. (2013), because soil pH regulates almost all biological and chemical reactions in soil, as well as the solubility of minerals and nutrients it is generally referred to as a master variable. Comparing the soil pH of the different land uses, it was observed that pH value in mango plantation > coffee plantation > cashew plantation > forest plantation > cocoa plantation and ranged from 6.707 to 7.120 (thus neutral to slightly alkaline).

Statistical analyses of the different land uses revealed that the soil pH significantly differed from each other. This finding is consistent with Tetteh (2017) where he reported of significantly different soil pH among the different farming systems of his study. Again, Djagbletey (2017) reported that, when natural forest is degraded or converted to agricultural use the soil pH significantly changes. He also attributed the variations observed to the low levels of cations with the attendant low organic matter content of the soils.

5.5 Effect of land use and season on soil microbial characteristics

5.5.1 Soil microbial biomass

Soil microbial biomass is an important factor that significantly and positively affects carbon storage in soil through the regulation of carbon sequestering, soil respiration, plant productivity and nutrient mineralization which plays a crucial role in the biogeochemical cycling of carbon (C), nitrogen (N), and phosphorus (P) in continental ecosystems (Bargalia *et al.,* 2018).

With recognition of the fact that the fertility status of soil is influenced by microbial biomass per unit soil organic carbon (Haripal and Sahoo, 2014) microbial biomass C, N and P were used as sensitive indicators for the evaluation of soil fertility in the different forest reserves.

5.5.1.1 Soil microbial biomass carbon (C_{mic})

In this study, significant differences ($p < 0.05$) were observed among the soil microbial biomass carbon (C_{mic}) of the different land uses. Mango plantation recorded the highest microbial biomass carbon (323.8 mg/kg) while cashew plantation (151.3 mg/kg) recorded the least. The significant differences among the land uses could be attributed to the significantly different litter accumulation under the different land uses and the different microclimate. This is consistent with Tetteh (2017), who observed that, the differences in $\mathbf{C_{mic}}$ under different cropping systems could be attributed to the changes in variable microclimates resulting from the differences in vegetation cover and actively growing vegetation. This is in conformity with Yin *et al.* (2016) who revealed that, the composition and structure of the microbial community are strongly related to abiotic and biotic factors, such as climate factors (e.g., temperature and precipitation), soil substrate properties (e.g., C and N pools) and tree species composition and diversity. Also, Deng (2016) reported that soil microbial biomass is affected by changes of soil water content (SWC), physical properties (clay and sand content), nutrient status (nitrogen and phosphorus) and quantity and quality of substrates (soil and litter C:N ratio).

Mango plantation recorded the highest C_{mic} probably because it recorded the highest carbon stock (Table 4.4) coupled with one of the highest volumetric moisture contents (Table 4.2). This confirms that soil microbial biomass strongly depends on the content of SOIL ORGANIC CARBON as stated by McGonigle and Turner (2017). Higher soil moisture contents under dense vegetation significantly affect the population of soil microbes as soil microorganisms usually respond negatively to low soil moisture (Bing-Cheng and Dong-Xia, 2012).

Also, mango plantation recording the highest C_{mic} could be as result of the high litter C:N ratio it recorded. Woloszczyka *et al.* (2020) reported that the highest C_{mic} being exhibited in forest soils suggests that the accumulation of nitrogen-poor and slowly degradable carbon compounds, such as lignin (which has high C:N ratio) hence provides a larger substrate for soil microbes to feed on and translates to high C_{mic}.

Apart from the effects of different land uses, microbial biomass carbon also depends on abiotic soil properties resulting from the physical and chemical qualities of the parent material. Soil texture is a factor that is suitable for distinguishing land-use groups into further sub-groups, and to consider sandy and loamy croplands separately, as well as the sandy, loamy and silty, and clayey grassland sites (Wiesmeier *et al.* 2015)

Comparison of the results of this study with those reported by Djagbletey (2017) for Savanna "forest reserve" soils in Northern Ghana and Tetteh (2017) for rubber/plantain agroforestry in Ghana" showed that the C_{mic} values of the different land uses in this study were higher. However, the results were consistent with Alfaro-Flores, Morales-Belpaire and Schneider (2015) in soils under five different cocoa plantation production systems in Alto Beni, Bolivia.

Significant differences of seasonal C_{mic} values were observed in this study. DS2016 (145.4 mg/kg) recorded the least microbial biomass carbon followed by DS2017 (159.1 mg/kg), MRS2016 (223.7 mg/kg), MNRS2016 (239.8 mg/kg) and MRS2017 (244.1 mg/kg) while MNRS2017 (260.4 mg/kg) recorded the highest microbial biomass carbon. It was observed that C_{mic} significantly decreased in the dry seasons (DS2016 and DS2017) and increased in the rain seasons (MRS2016, MRS2017, MNRS2016 and MRS2017) of the study. This can be attributed to the fact that during the rain seasons adequate soil moisture contents promote the activities of soil microbes. A lack of soil water diminishes nutrient availability by reducing microbial activity, which is responsible for the liberation of nitrogen, phosphorus and sulphur from soil organic matter (Babur and Dindaroglu, 2020). This variation might be due to fluctuations in soil water leading to differential litter decomposition and subsequently nutrient mineralization. Again, the observed significant variations could be as a result of the fluctuations in soil temperature, rainfall, humidity and sunshine. Bolat *et al*. (2015) found that, seasonal fluctuations in temperature, moisture and humidity showed significant effects on microbial indexes such as microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), and microbial biomass phosphorus (MBP) in the forest floor and soil.

An interaction between the C_{mic} of seasons and different land uses were observed. This illustrates that, soil microbial community structure varies with seasonal changes and tree species affect soil microbial community composition by changing the soil physicochemical properties (Babur and Dindaroglu, 2020).

5.5.1.2 Soil microbial biomass nitrogen (N_{mic})

The size of microbial populations in soil, especially the microbial biomass Carbon (C_{mic}), Nitrogen (N_{mic}) and Phosphorus (P_{mic}) has been introduced as a sensitive indicator of soil function, which plays a very important role in C, N, and P dynamics of forest ecosystems (Kooch., Moghimian and Kolb, 2019).

The study indicated that, mango plantation recorded the highest Microbial biomass Nitrogen (N_{mic}) value (47.32 mg/kg) followed by coffee plantation (35.63 mg/kg), forest stand (24.79 mg/kg), cocoa plantation (24.44 mg/kg) with cashew plantation (22.28 mg/kg) recording the least vale of soil microbial biomass. Mango plantation and coffee plantation were significantly different ($p < 0.05$) from forest stand and cocoa plantation and cashew plantation. Cocoa plantation was not significantly different ($p < 0.05$) from both forest stand and cashew plantation; however, forest stand was significantly different from cashew plantation. The N_{mic} values of the land uses apart from the forest stand indicates that when cash tree crops are well managed after conversion from natural forest, they do not only mimic the qualities of the natural forest but can perform better as reported by Young (2017) that tree crops are able to mimic the natural forest by providing similar environmental condition of a natural forest.

The soil microbial biomass nitrogen ranged from 16.73 mg/kg to 44.46 mg/kg with DS2016 recording the least soil microbial biomass nitrogen followed by DS2017 while MNRS2017 recorded the highest value. N_{mic} like C_{mic} followed a similar trend where N_{mic} of the dry seasons (DS2016 and DS2017) decreased while that of rain seasons (MRS2016, MRS2017, MNRS2016 and MRS2017) steadily increased. This is consistent with He *et al.* (2020), who reported that the dry season leads to a decrease of soil C_{mic} content and N_{mic}. They attributed the decrease of soil C_{mic} and N_{mic} content to the decline in substrate (SOC, litter) and soil moisture during the dry season.

5.5.1.3 Microbial biomass phosphorus (P_{mic})

Microbial biomass is also an early indicator of changes in total organic C. Unlike total organic C, microbial biomass C responds quickly to management changes. In a long-term trial at Merredin, Western Australia, no significant change in total organic C was detected between stubble burnt or retained plots after 17 years yet microbial biomass C in the same plots had increased from 100 to 150 kg C/ha (Hoyle *et al*., 2006).

Unlike in the case of C_{mic} and N_{mic}, the forest stand recorded the least microbial biomass phosphorus P_{mic} among the different land uses. P_{mic} ranged from 7.89 mg/kg to 25.5 mg/kg. Again, the significant difference of P_{mic} observed among the different land uses could be attributed to different microclimate provided by the different land uses as reported by Djagbletey (2017) for Savanna "forest reserve" soils in Northern Ghana and Tetteh (2017) for rubber/plantain agroforestry in Ghana. Forest stand recorded the least P_{mic} because soils under the forest stand recorded a relatively higher proportion of sand (77-85.18%) particles. Carson (2012), explained that very sandy soils, means organic matter is broken down rapidly if there is sufficient moisture and hence leaves microbial biomass starved

Seasonality plays an important role in microbial C, N and P turnover and it indicates the dynamic nature of C and N circulation on the land use floor and the importance of microbial populations for nutrient conservation, regeneration and management (Dawoe, 2009).

Significant differences were observed among the seasonal soil microbial biomass Phosphorus (P_{mic}) values. DS2017 (18.45 mg/kg) recorded the highest microbial biomass phosphorous while MRS2016 (12.97 mg/kg) recorded the least. Unlike in the case of seasonal C_{mic} and N_{mic}, P_{mic} was highest in the dry seasons (DS2016 and DS2017) and lowest in the rain seasons (MRS2016 and MRS2017, MNRS2016 and MRS2017). This could be as a results of the massive vegetation growth by all the land uses at the onset of the rains and during the rains, hence strong demand for and utilization of these nutrients by the trees that grow vigorously during the rainy period (Singh and Yadava, 2006). Likewise, Dawoe (2009), reported that, the decrease in P_{mic} of soils under the natural forest stand and cocoa plantation during the rainy season could be attributed to the strong demand for nutrient for optimal plant growth during the onset and peak of the rain season.

5.5.2. Soil microbial quotient

Microbial quotient is the ratio of microbial biomass to soil organic carbon and indicates how efficiently soil organic matter is being used by microorganisms (Pankhurst *et al*., 2002; Carson, 2012).

5.5.2.1 Soil microbial quotient carbon (qC_{mic})

Mango plantation (1.4394 %) recorded the highest microbial quotient carbon (qC_{mic}) followed by coffee plantation (1.0535 %), cocoa plantation (0.7796 %) and cashew plantation (0.6766 %) while forest stand (0.6385 %) recorded the least. Apart from forest stand and cashew plantation which were not significantly different ($p < 0.05$) from each other all the other land uses were significantly different ($p < 0.05$) from each other. When the results of this study were compared to that of Deng *et al*. (2016) and Anderson *and Domsch* (2010), who reported of soil microbial quotient carbon (qC_{mic}) 2.3 % for monoculture soils and 2.9 % for crop rotation soils respectively, it was observed that the values were relatively lower. However, He *et al.* (2020) in their study on "soil microbial community and its interaction with soil carbon dynamics following a wetland drying processes" reported a qC_{mic} in a range of 0.20–0.30 % in June and in a range of 0.24–0.42 % in October which were much lower than what was reported in this study. Also, the results of this study were consistent with Djagbletey (2017) who reported of a qC_{mic} of 0.67-2.17 % in his study of carbon stocks and soil nutrients characteristics of selected forest reserves in the Guinea Savanna Agroecological Zone of Ghana.

The forest stand recorded the lowest qC_{mic} probably because of the high sand content it contained (Appendix D). This assertion was confirmed by Deng *et al*. (2016) who reported that, lower qC_{mic} indicated that soil microbes were stressed because of lower SOC and higher sand content in soil. Same reason can be assigned to mango plantation which recorded the least sand content hence the highest value of qC_{mic}. The highest value of qC_{mic} recorded by mango plantation is an indication of the efficiency in the utilization of organic substrates by microbes (Anderson, 2003) and could conserve soil organic carbon. Also, as reported by Bünemann (2018) soil microbial quotient carbon (MBC: SOC ratio) is an important indexes of soil quality and soils with higher MBC: SOC ratios could have stronger ability to conserve soil organic carbon.

As expected, significant differences were observed among the different seasonal values of qC_{mic}. MNRS2017 (1.0923 %) recorded the highest microbial quotient carbon followed by MNRS2016 (1.0404 %), MRS2017 (1.0379 %), MRS2016 (0.9899), DS2017 (0.6914 %) with DS2016 (0.6532 %) recording the least microbial quotient carbon. It was observed that similar seasons like dry season (DS2016 and DS2017), major rain season (MRS2016 and MRS2017) and minor rain season (MNRS2016 and MNRS2017) recorded similar results hence they were not significantly different ($p < 0.05$) from each other. The low qC_{mic} recorded by the dry seasons can be attributed to the soil moisture stress during the dry season and hence negatively affected the activities of soil microbes. Manzoni *et al.* (2012) reported that reduced water availability during the dry season could limit substrate diffusivity and accessibility for soil microbes, and thus inhibit microbial growth.

5.5.2.2 Microbial quotient Nitrogen (qN_{mic})

According to Sparling (1992) and Woloszczyka *et al.* (2020) soil microbial quotient serves as a more sensitive indicator of changes in the carbon dynamics than do the content of SOC and MBC separately.

In this study cashew plantation (0.525 %) recorded the least microbial quotient nitrogen (qN_{mic}) followed by forest stand (0.775 %), coffee plantation (0.847 %) and cocoa plantation (1.082 %) while mango plantation (2.508 %) recorded the highest.

This could have been as a result of the relatively low soil and litter C: N recorded by cashew plantation and therefore the substrate which is the source of energy for microbes easily got depleted. Deng *et al.* (2016) confirms this assertion that, quantity and quality of substrates (soil and litter C: N ratio) positively correlates with soil microbial quotient. Also, Woloszczyka *et al.* (2020), reported that the highest C/N ratios being exhibited in forest soils suggests the accumulation of nitrogen-poor and slowly degradable carbon compounds, such as lignin hence provides a larger substrate for soil microbes to feed on. Therefore, cashew plantation with a lower C: N ratio will have small substrate for soil microbes to feed on. The results of this study are consistent with Zhu *et al.* (2010), who reported of a qN_{mic} of 0.84 to 1.74 % when they compared soil microbial quotient nitrogen (qN_{mic}) between natural secondary forest and Larix olgensis plantations.

Babur and Dindaroglu (2020), concluded that, soil microbial community structure would vary with seasonal changes and tree species affect soil microbial community composition by changing the soil physicochemical properties. Likewise, in this study, it was found that similar season thus dry seasons (DS2016 and DS2017), major rain seasons (MRS2016 and MRS2017) and minor rain seasons (MNRS2016 and MNRS2017) were not significantly different from each other as they recorded similar rainfall amount, temperature, humidity and sunshine intensity. The seasonal soil microbial quotient nitrogen (qN_{mic}) ranged between 0.696 % and 1.571% with MNRS2017 (1.571 %) recording the highest Microbial quotient nitrogen value while DS2016 (0.696 %) recorded the least microbial quotient nitrogen.

5.5.2.3 Microbial quotient Phosphorous (qP_{mic})

Mango plantation (0.009489 %) recorded the highest microbial quotient phosphorous (qP_{mic}) value while cashew plantation (0.003029 %) recorded the least followed by forest stand (0.003149 %), cocoa plantation (0.00482 %) and coffee plantation (0.008172 %). But for cashew plantation and forest stand which were not significantly different ($p < 0.05$) from each other, all the other land uses were significantly different ($p < 0.05$) from each other. Similar reasons given for microbial quotient nitrogen (qN_{mic}) can also be given for microbial quotient Phosphorous (qP_{mic}). Again, mango plantation recorded the highest microbial quotient Phosphorous (qP_{mic}) because it recorded the highest P_{mic} (Table 4) and the highest available phosphorus (Table 5). Contrary to the results of this study, Zhu *et al.* (2010), reported that natural secondary forest stand did record a higher qP_{mic} when it was compared with Larix olgensis plantations in their work comparison of soil microbial biomass C, N and P between natural secondary forests and Larix olgensis plantations under temperate climate.

For seasonal microbial quotient phosphorous, MRS2016 (0.00496 %) recorded the least value followed by MRS2017 (0.004979 %), MNRS2017 (0.005556 %), MRS2017 (0.005586 %) and DS2016 (0.006271 %) while DS2017 (0.007039 %) recorded the highest microbial quotient phosphorous. It was observed that the dry seasons (DS2016 and DS2017) recorded the highest qP_{mic} followed by the minor rain seasons (MNRS2016 and MNRS2017) and the major rain seasons recorded (MRS2016 and MRS2017) the least in the respective years. DS2016 and DS2017 were significantly different from all the other seasons however MRS2017 and MNRS2017 were not significantly different ($p < 0.05$) from each other but were significantly different from MRS2016 and MNRS2016 which were not significantly different ($p < 0.05$) from each other. This result is consistent with Dawoe (2009) who reported that, the decrease in P_{mic} of soils under the natural forest stand and cocoa plantation during the rainy season could be attributed to the strong demand for nutrient for optimal plant growth during the onset and peak of the rain season.

5.5.3 Soil microbial ratio

5.5.3.1 Soil microbial biomass Carbon to Nitrogen ratio (C_{mic}: N_{mic})

According to Singh and Yadava (2006), soil microbial C: N ratio is often used to describe the structure and the state of the microbial community. Jenkinson & Ladd (1981), reported that, fungi and bacteria have considerably different microbial C: N ratio i.e. ratio of the fungal hyphae is often 10-12 and that of bacteria usually between 3-5.

In this study, significant differences were found among soil microbial biomass carbon to nitrogen ratio (C_{mic}: N_{mic}) of the different land use. The C_{mic}: N_{mic} ranged from 6.392 to 8.154, with coffee plantation recording the highest microbial biomass carbon to nitrogen ratio while forest stand recorded the least soil microbial biomass carbon to nitrogen ratio. The significant differences could be as a result of the variability in soil microbial carbon (C_{mic}) and soil microbial nitrogen (N_{mic}) recorded by the different land uses and the effect of the different tree species on soil microbial community composition. This conforms with Babur and Dindaroglu (2020) who reported that soil microbial community structure would vary with different tree species and affect soil microbial community composition by changing the soil physicochemical properties.

Using Jenkinson and Ladd (1981) as a standard, the microbial structure of the different land use in this study is predominately controlled by fungi as their C_{mic}: N_{mic} ranged between 6.392 and 8.154. This is also consistent with Campbell *et al.* (1991) and Dawoe (2009), who reported that, a high microbial C: N ratio indicates that the microbial biomass contains a higher proportion of fungi, whereas low value suggested that, bacteria predominate in the microbial population. Also, the results of this study, falls within the C_{mic}: N_{mic} range reported by Djagbletey (2017) who recorded mean C_{mic}: N_{mic} ratios ranging from 5.85 to 17.71 in his study of forest reserves in the guinea savanna agro-ecological zone of Ghana. Again, Logah *et al.* (2013) reported C_{mic}: N_{mic} ratios ranging from 3.9 to 35 in an agricultural land in the semi-deciduous forest zone of Ghana. It also conforms to Xu, Thornton and Post (2013) who reported that the global C:N ratio of the soil microbial biomass scale converges towards 6–8.

Seasonal C_{mic}: N_{mic} range between 5.941 and 8.856. MNRS2017 recorded the least season value of C_{mic}: N_{mic} while DS2016 (8.856) recorded the highest C_{mic}: N_{mic}. The results showed that similar seasons like first and second Dry Seasons (DS2016 and DS2017), first and second Major rain Seasons (MRS2016 and MRS2017) and first and second minor rain seasons (MNRS2016 and MNRS2017) were not significantly differently ($p < 0.05$) from each other but were significantly different ($p < 0.05$) from different Seasons.

It was also observed that drier seasons recorded relatively higher C_{mic}: N_{mic}. This could be as a result of predominate presence fungi in the soil microbial structure and fungi ability to adapt to drier environment than bacterial. This assertion is confirmed by He *et al*. (2020) who suggested that soils with increasing aridity favour a fungal-rich microbial community, since fungi were able to overcome better the disadvantages of drier conditions than bacteria. Again, the highest C_{mic}: N_{mic} value recorded in the dry season can be attributed to the stronger C conserve ability of fungi than bacteria Zhu *et al.* (2010) because fungi are also known to have slower biomass turnover rates than bacteria hence are not able to easily break down litter to release carbon (Six *et al.,* 2006).

The significant differences among the season can also be attributed to the different amount of rainfall during the difference seasons. This is supported by Pabst *et al.* (2016) who reported that soil microbial ratio in forest stands can be affected by different soil moisture content. Water is critical for the living of microbes and therefore, soil water content significantly affects soil microbes in both dry and wet environment (Maestre *et al.,* 2015).

5.5.3.2 Soil microbial biomass Carbon to Phosphorus ratio (C_{mic}: P_{mic})

Microbial biomass and its C: N/P ratios reflect the degree of immobilization of carbon and nitrogen (Dawoe, 2009). A decrease in soil microbial biomass could result in mineralizing of nutrients, while an increase in microbial biomass may lead to immobilization of nutrients (Kooch, Mehr and Hosseini 2020).

The results of this study indicated that, coffee plantation (11.94) recorded the least value for Soil microbial biomass carbon to Soil microbial biomass phosphorous ratio (C_{mic}: P_{mic}) followed by mango plantation (13.06), cocoa plantation (16.99) and cashew plantation (19.36) while forest (19.77) recorded the highest value of C_{mic}: P_{mic}. Forest stand recorded the highest C_{mic}: P_{mic} probably because it recorded the least P_{mic} (Table 4.5) hence the observation. Likes wise coffee plantation recorded the least C_{mic}: P_{mic} because it recorded the highest P_{mic}.

Although, forest recorded the highest C_{mic}: P_{mic} it was relatively low when compared with Djagblety (2017) who reported that the KeniKeni and Klupene forest recorded a mean C_{mic}: P_{mic} of 38.89 and 44.1 respectively. However, the results of this study were higher when compared with Kooch, Mehr and Hosseini (2020) who reported of a C_{mic}: P_{mic} ratio range of 5.25-6.24 in their work "the effect of forest degradation intensity on soil function indicators in northern Iran". Also, Tetteh (2017) reported of an initial soil C_{mic}: P_{mic} of 0.77 and 18.48 at the Ellembelle and Jomoro sites respectively

The results indicated that, DS2017 (9.39) recorded the least value for soil microbial biomass carbon to soil microbial biomass phosphorous ratio (C_{mic}: P_{mic}) while MNRS2016 (20.92) recorded the highest value C_{mic}: P_{mic}. DS2017 and DS2016 were significantly different ($p < 0.05$) from all other season but were not significantly different ($p < 0.05$) from each other. As high as 116 % increase in C_{mic}: P_{mic} was observed from the first dry season (DS2016) to the first minor rain season (MNRS2016). Generally, it was observed that C_{mic}: P_{mic} decrease very significantly in the dry season but increased in the rain seasons. This is because the dry seasons (DS2016 and DS2017) of this experiment recorded the highest P_{mic} and hence a lower C_{mic}: P_{mic}.

5.5.3.3 Soil microbial biomass Nitrogen to Phosphorus ratio (N_{mic}: P_{mic})

Land use values of soil microbial biomass nitrogen to microbial biomass phosphorous ratio (N_{mic}: P_{mic}) values were significantly different from each other. Coffee plantation (1.73) recorded the least value of N_{mic}: P_{mic} while forest stand (3.09) recorded the highest value. This observation can be attributed to the fact that forest stand and coffee recorded the least and highest P_{mic}, (Table 4.5) respectively, hence the trend. The results of this study are relatively higher when compared with Kooch, Mehr and Hosseini (2020) who reported a N_{mic}: P_{mic} range of 0.58 to 0.69 and Tetteh (2017) who reported of an initial soil N_{mic}: P_{mic} of 0.31 and a N_{mic}: P_{mic} range of 0.24 to 0.48 among the five different land use systems of his work at the Elembelle site. However, N_{mic}: P_{mic} vales of this study are consistent with Djagbletey (2017) who reported a mean of N_{mic}: P_{mic} of 3.48, 1.36 and 5.8 for Kenikeni, Sinsablegbinni and Klupene forest reserves respectively.

The highest soil microbial biomass nitrogen to microbial biomass phosphorous (N_{mic}: P_{mic}) ratio value was recorded by MNRS2016 (3.30), followed by MNRS2017 (3.24), MRS2016 (2.78), MRS2017 (2.73), and DS2017 (1.25) while Season (1.24) recorded the least value of N_{mic}: P_{mic} ratio. It was observed that similar seasons thus DS2016: DS2017, MRS2016: MRS2017 and MNRS2016: MNRS2017 were not significantly differently ($p < 0.05$) from each other but were significantly different ($p < 0.05$) from different Seasons. Again, there were about 125% and 167% increase in N_{mic}: P_{mic} ratio from DS2016 to MRS2016 and MNRS2016 respectively. However, there was about 18% increase N_{mic}: P_{mic} from MRS2016 to MNRS2016.This result could be as a result of the crucial role seasonal temperature, humidity and rainfall plays in the amount of soil microbial biomass and its ratios. Yuste *et al.* (2011) study showed that, decreasing moisture in soil could affect microbial community structure by influencing substrate quality.

The results of this study are consistent with Dawoe (2009), who reported of significant difference between the seasonal N_{mic}: P_{mic} of the rain season and the dry season. He also, reported a seasonal N_{mic}: P_{mic} of 6.31, 2.00, 4.1 and 3.40 for forest, a 3 year cocoa plantation, 15 year cocoa plantation and 30 year cocoa plantation in the rain season respectively while he reported a seasonal N_{mic}: P_{mic} of 1.13, 0.65, 1.75 and 0.64 for forest, a 3 year cocoa plantation, 15 year cocoa plantation and 30 year cocoa plantation for the dry season respectively. Also, Babur (2018) revealed that the amounts of microbial population and activity significantly changed with the seasons and followed a sequence order (summer > autumn > spring > winter) because of the different temperature, humidity and rainfall.

5.6 Relationships among soil physical, chemical, hydraulic and microbial properties.

5.6.1 Relationship between soil bulk density and other soil physical, hydraulic and soil carbon accumulation

Generally, there were significant negative relationship between bulk density and aggregate stability, total porosity, steady state infiltrability, infiltration amount and soil organic carbon. This means that high bulk density reduces total pores in a soil and therefore affects the amount of water that can enter and be transmitted in the soil. Also, high bulk density decreases steady state infiltrability which is a point of infiltration rate that when extra water is added to the soil, it will lead to flooding and run off depending on the kind of slope of the soil. The correlation between bulk density and soil carbon stock was however significantly positive. This result indicates that high bulk density of soils promotes more soil organic carbon storage as it provides a better habitat for soil carbon storage and probably provided physical barriers to help in the stabilization of carbon hence the relatively high carbon stock associated with soils high bulk densities as reported by Djagbletey (2017).

5.6.2 Relationship between soil organic carbon and some soil physical and hydraulic properties

In this study, a positive correlation between soil organic carbon and aggregate stability, bulk density, carbon stock, infiltration amount and saturated hydraulic conductivity were revealed. This suggest that, as soil organic carbon contents increases it increases the soils particles ability to resist breakage by rain drops, increase soil carbon storage as in stocks, and increase the amount of water that enters and can be transmitted by the soil (Osei *et al*., 2017).

5.6.3 Relationships among soil chemical and microbial properties.

Soil microbial C/N/P stoichiometry ratios are important for ecosystem fluxes of C, N, and P, such as mineralization and immobilization (He *et al.,* 2020). According to these authors, the ratios can help to characterize the cycling of soil elements, especially regarding soil C sequestration. In this study, a positive correlation was found between available phosphorus and soil microbial biomass phosphorus and microbial quotient phosphorus. This means that as available phosphorus increases in the soil, soil microbes make very efficient use of it and speeds up mineralization. Microbial C: P ratio and Microbial N: P ratio correlated positively with soil organic carbon which means that as soil organic carbon increases in the soil degree of immobilization of carbon and nitrogen also increases as reported by Dawoe, (2009).

However, a significantly negative correlation was found between total nitrogen and microbial biomass nitrogen and microbial quotient nitrogen. This means that as total nitrogen in the soil increases, microbial biomass nitrogen decreases with a decrease in its efficient usage by soil microbes. As a decrease in soil microbial biomass could result in mineralizing of nutrients, while an increase in microbial biomass may lead to immobilization of nutrients (Kooch, Mehr and Hosseini 2020).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6. 1 Conclusion

When a forest is cleared to produce more food and raw materials to meet the needs of the growing world population, its soil physical, chemical and hydrological properties degrade.

The study showed that, when forests are cleared for different agricultural land uses, significant differences occur among the bulk densities of soils under the different agricultural uses. The soils under mango plantation recorded the highest bulk density, the least total porosity and least air-filled porosity.

The study showed that, forest stand (reference point) recorded the highest cumulative infiltration amount, sorptivity, infiltration rate, steady state infiltrability and saturated hydraulic conductivity followed by coffee, cocoa, cashew and mango plantations. This means that soils under forest > coffee > cocoa > cashew > mango can take in, absorb and transmit water in this order. It also means that soils under forest stand will take the longest time to saturate and flood or run off depending on the slope of the soil because it allows more water entry from the surface of the soil, absorb more infiltrated water and transmit more water within the soil. Significant seasonal variations were recorded among the different seasons in cumulative infiltration amount, sorptivity, infiltration rate and saturated hydraulic conductivity but not in steady state infiltrability.

Litter fall and soil organic carbon (SOC) significantly differed among the different land use. Seasonal variations were observed in both litter fall and SOC. Litter fall was highest in the dry seasons (DS2016, DS2017) and lowest in the minor rain seasons (MNRS2016, MNRS2017). No significant difference was observed among soil carbon stocks and soil carbons sequestration of the soils under the different land uses. Likewise, no seasonal variation was observed because it takes relatively a longer time than the three years of the research for carbon accumulation to be noticed.

Soil chemical properties showed that, soils under the different land uses were moderate to high in nutritional status. Significant seasonal variability was oberved in total nitrogen and available phosphorus but not in exchangeable bases.

A significant negative relationship was observed between bulk density and aggregate stability, total porosity, steady state infiltrability, infiltration amount and soil organic carbon. The correlation between litter fall and aggregate stability, infiltration amount and steady state infiltrability were significantly positive while the correlation between litter fall and available phosphorus, microbial biomass nitrogen and microbial biomass carbon were however significantly negatively correlated.

The study has contributed to knowledge on the effect of seasons and different agricultural land uses on soil hydraulic and hydrological properties which were not critically assessed in earlier studies. It has also added to the body of knowledge on the seasonal quantities of litter fall from cocoa, coffee, cashew and mango plantations and their influence on soil carbon sequestration and hydro-physical properties. The study has provided knowledge on temporal changes in soil organic carbon and soil microbial dynamics due to different agricultural land uses and seasonal variability. Finally, the study has set the bases for other tree crops to be used to achieve the same or similar effect on soil and water conservation, while improving carbon sequestration in the face of climate change in Ghana.

6.2 Recommendation

Based on these conclusions, it is suggested that, mango, cashew, cocoa and coffee could be used to store and sequester as much carbon as the forest since these different agricultural land uses can mimic the natural forest when they are properly mangaged and prevented from bush fires.

To improve soil hydrological and hydraulic properties after a forest has been cleared, it is recommended that these tree crops could be planted in this order of efficiency coffee > cocoa > cashew > mango.

Further studies are needed to establish the relationship between forest or tree hydrology and surface soil hydrology of different agricultural land uses.

It is also suggested that the study could be repeated in other agro-ecological zones of Ghana specifically, the Deciduous forest and Rain Forest Zones to confirm the influence of agricultural land uses and seasons on soil carbon accumulation, hydro-physical, chemical and microbial properties of the soil in those agro ecological zones in the country.

REFERENCES

Abdullahi, G. (2011) Perception of Ghanaian mango farmers on the pest status and current management practices for the control of the African invader fly Bactrocera invadens (Diptera: Tephritidae) as published by New York Science Journal, 2011; 4(2)

Alfaro-Flores, A., Morales-Belpaire, I. & Monika Schneider (2015). Microbial biomass and cellulase activity in soils under five different cocoa production systems in Alto Beni, Bolivia. Agroforest Syst DOI 10.1007/s10457-015-9812-z.

Adhikari, K., Carre F., Toth, G. & Montanarella, L. (2009). Site Specific Land Management: General Concepts and Applications. JRC Scientific and Technical Reports, EUR23978 EN – 2009.

Ago, E. (2016). Dynamique des flux de carbone entre l'atmosphère et des écosystèmes ouest-africains: cas des forêts et savanes sous climat soudanien au Bénin. Thèse de doctorat. Université de Liège – Gembloux Agro Bio Tech, Belgique, 184 p.

Ahmed, O. H., Husni, M. M., Hanafi, M. M., Seyed Omar, S. R. & Anur, A.R. (2000) Macronutrient distribution and cycling of Pineapple planted on tropical peat. Pertanika Jor. Trop. Agric. Sci. 2000;23 (2):89-95.

Alam, M. K., Salahin, N., Islam, S. & Begum, R. (2017). Patterns of change in soil organic matter, physical properties and crop productivity under tillage practices and cropping systems in Bangladesh. J Agr Sci.155:216-238.

Alvarez, R. & Alvarez, C.R. (2000). Soil organic matter pools and their association with carbon mineralization kinetics. Soil Science Society of America Journal, 64(1): 184-189.

Anderson, J. M. & Ingram, J. S. I. (1998). Tropical Soil Biology and fertility: A handbook of methods. CAB Int. UK. 82-89pp.

Anderson, J. M. & Ingram, J. S. I. (1998). Tropical Soil Biology and Fertility. A handbook of methods. (eds.). Pp. 1-221.

Anderson, T. H. & Domsch, K. H. (2010). Soil microbial biomass: The eco-physiological approach. Soil Biol. Biochem. 2010, 42, 2039–2043.

Anderson, T. H. (2003). Microbial eco-physiological indicators to asses soil quality. Agriculture, Ecosystems and Environment 98 285–293, doi:10.1016/S0167-8809(03)00088-4.

Anim-Kwapong, G. & Frimpong, E. (2005). Vulnerability of agriculture to climate change-impact of climate change on cocoa production. Final Report submitted to the Netherlands climate change studies assistance programme: NCAP; 2005. 2.

Assefa, F., Elias, E., Soromessa, T. & Ayele, G. T. (2020). Effect of changes in land-use management practices on soil physicochemical properties in Kabe watershed, Ethiopia. Air, Soil and Water Research Volume 13: 1–16 DOI: 10.1177/1178622120939587. atmospheric excess atmospheric carbon dioxide. Unasylva 41: 12-21.

Attakorah, K. (2020). Genotype x environment interaction and yield stability analysis of some cowpea varieties released in Ghana from 1990 to 2005. [PhD. thesis] Department of Crop and Soil Sciences Education, College of Agriculture, University of Education Winneba, Ghana.

Awotoye, O. O., Adebola, S. I. & Matthew, O. J. (2013). The effects of land-use changes on soil properties in a humid tropical location; Little-Ose forest reserve, south-western Nigeria. Research Journal of Agricultural and Environmental Management, 2(6): 176-182.

Ayoubi, S., Khormali, F., Sahrawat, K. L. & Rodrigues de Lima, A. C. (2011). Assessing impacts of land use change on soil quality indicators in a loessial soil in Golestan province, Iran," Journal of Agricultural Science and Technology, vol. 13, pp. 727–742.

Babur, E. (2018). Determination of carbon and nitrogen stock in forest floor and soil of even-aged black pine, lebanon cedar and oriental beech forest in karstic ecosystems; monitoring of seasonal changes in some microbial properties [PhD. thesis]. Graduate School of Natural and Applied Sciences, Department of Forestry Engineering. Turkey: Kahramanmaraş Sütçü İmam University (in Turkish).

Babur, E. (2019). Effects of parent material on soil microbial biomass carbon and basal respiration within young afforested areas. Scandinavian Journal of Forest Research. 43(2):94-101.

Babur, E. & Dindaroglu, E (2020). Seasonal Changes of Soil Organic Carbon and Microbial Biomass Carbon in Different Forest Ecosystems, Environmental Factors Affecting Human Health, Ivan Uher, Intech Open, DOI: 10.5772/intechopen.90656. Available from: https://www.intechopen.com/chapters/71739

Babur, E. & Dindaroglu, T. (2020). Seasonal Changes of Soil Organic Carbon and Microbial Biomass Carbon in Different Forest Ecosystems. Environmental Factors Affecting Human Health. Intech Open. A book chapter DOI: http://dx.doi.org/10.5772/ intechopen.90656.

Bachar, A., AL-Ashhab, A., Soares, M. I. M., Sklarz, M. Y., Angel, R., Ungar, E. D. & Gillor, O. (2010). Soil microbial abundance and diversity along a low precipitation gradient. Microb. Ecol. 2010, 60, 453–461.

Baldock, J.A. (2007). Composition and cycling of organic C in soil. In Marschner, P., Rengel, Z. (Eds.), Nutrient Cycling in Terrestrial Ecosystems. Springer Verlag, Berlin Heidelberg, pp.1-35.

Ball, J.B. (2001). Global forest resources: history and dynamics. In the Forests Handbook. Vol. 1, ed. J Evans, pp. 3–22. Oxford: Blackwell Sci. 418 pp.

Bargalia, K., Manrala, V., Padaliaa, K., Bargalia, S.S. & Upadhyayb, V.P. (2018). Effect of vegetation type and season on microbial biomass carbon in central Himalayan forest soils, India. Catena. 171: 125-135.

Barrow, N. J. & Shaw, T. C. (1975). The slow reactions between soil and anions: Effect of time and temperature on the decrease in phosphate concentration in the soil solution. Soil Science 119: 167-177.

Barrow, N. J. & Shaw T. C. (1975). The slow reactions between soil and anions: 2. Effect of time and temperature on the decrease in phosphate concentration in the soil solution. Soil Science 119: 167-177.

Barto, E. K., Alt, F., Oelmann, Y., Wilcke, W. & Rillig, M. C. (2010). Contributions of biotic and abiotic factors to soil aggregation across a land use gradient, Soil Biol. Biochem. 42, 2316–2324.

Bastin, J.-F., Berrahmouni, N., Grainger, A., Maniatis, D., Mollicone, D., Moore, R., Patriarca, C., Picard, N., Sparrow, B., Abraham, E.M., (2017). The extent of forest in dry land biomes. Science 356, 635–638.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. & Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agricultural Systems, 94, 1, 13 – 25.

Batjes, N. H. (2011). Soil organic carbon stocks under native vegetation – revised estimates for use with the simple assessment option of the Carbon Benefits Project system. Agriculture, Ecosystems & Environment, 142, 365-373.

Batjes, N. H. (1996). Total carbon and nitrogen in soils of the world. European Journal of Soil Science, 47:151-63.

Batjes, N. H. (1996). Total carbon and nitrogen in soils of the world. European Journal of Soil Science, 47:151-63.

Battin, T.J., Luyssaert, S., Kaplan, L. A., Anthony K. Aufdenkampe, A. K., Richter, A. & Tranvik. L.J. (2009). The boundless carbon cycle. Nature geoscience | VOL 2 | SEPTEMBER 2009 | www.nature.com/naturegeoscience. Macmillan Publishers Limited

Bessah, E. (2014). Assessment of soil organic carbons stocks under various land use/land cover types in kintampo north municipal, Ghana. August 2014 DOI: 10.13140/RG.2.2.26256.25602. Thesis for: Master of Technology (M. Tech).

Bhavya, V.P., Anil-Kumar, S., Shiva-Kumar, K.M., Alur, A. & Shivanna, M. (2019). Land use systems to improve carbon sequestration in soils for mitigation of climate change International Journal of Chemical Studies 2017; 5(4): 2019-2021.

Binam, J.N., Gockowski, J. & Nkamleu, G. B. (2008). Technical Efficiency and Productivity Potential of Cocoa Farmers in West African Countries, The Developing Economies, XLVI-3, p. 242-63, 2008.

Bing-Cheng, Y. U. A. N. & Dong-Xia, Y. U. E. (2012). Soil microbial and enzymatic activities across a chronosequence of Chinese pine plantation development on the Loess Plateau of China. Pedosphere 22, 1–12.

Biro, K., Pradhan, B., Buchroithner, M. & Makeschin, F. (2013). Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan. Land Degrad Dev. 24:90-102.

Bispo, A., Andersen, L., Angers, D. A., Bernoux, M., Brossard, M., Cécillon, L., Comans, R. N. J., Harmsen, J., Jonassen, K., Lamé, F., Lhuillery, C., Maly, S., Martin, E., Mcelnea, A. E., Sakai, H., Watabe, Y. & Eglin, T. K. (2017). Accounting for Carbon Stocks in Soils and Measuring GHGs Emission Fluxes from Soils: Do We Have the Necessary Standards? Front. Environ. Sci. 5:41. doi: 10.3389/fenvs.2017.00041.

Bizuhoraho, T., Kayiranga, A., Manirakiza, N. & Mourad, K. A. (2018). The effect of land use systems on soil properties; a case study from Rwanda. Sustainable Agriculture Research, vol. 7, no. 2, pp. 30–40.

Black, C. A. (1986). Methods of soil analysis, Part I. Physical and mineralogical properties, including statistics of measurement and sampling. Part II. Chemical and microbiological properties. Agronomy series, ASA, Madison. Wis. USA.

Blagodatskii, S. A., Bogomolova, I. N. & Blagodatskaya, E. V. (2008). Microbial biomass and growth kinetics of microorganisms in chernozem soils under different land use modes. Microbiology 77, 99–106. https://doi.org/10.1134/S0026261708010141.

Blake, G. R. & Hartge, K. H. (1986). Bulk density, In methods of soil analysis. Pt 1 Agro Series. No 9. American Society Agronomy. NC. Madison, Wisconsin, U. S.A.

Blanco, J. A., Lo, Y. H., Welham, C. & Larson, B. (2017). Productivity of forest ecosystems. In: Innes J, Tikina A, editors. Sustainable Forest Management: From Principles to Practice. London: Earthscan.

Boillereau, N. & Adam, B. (2007). Cashew processing, marketing and consumption in West Africa: current status and opportunities. WATH/Accra technical report No. 22, United States Agency for International Development - USAID. http: //www. watradehub.com/sites/default/files/resourcefiles pdf. Accessed on 04 March 2018.

Bolat, İ., Şensoy, H. & Özer, D. (2015). Short term changes in microbial biomass and activity in soils under black locust trees (Robinia pseudoacacia L.) in the northwest of Turkey. Journal of Soils and Sediments. 15:2189-2198.

Bonsu, M., Adukpo, D. C. & Adjei–Gyapong, T. (2008) Estimates of CO2 emissions from soil organic carbon for different land uses. Africa and the Carbon Cycle Proceedings of the Open Science Conference on “Africa and Carbon Cycle: The Carbon Africa project “Accra (Ghana) 25-27 November 2008. World Soil Resources Reports No. 105. FAO (2011), Rome.ISBN 978-92-5-106887-8.

Bonsu, M., Adukpo D. C., & Adjei–Gyapong, T. (2011). Estimates of CO_2 emissions from soil organic carbon for different land uses. In: Bombelli, A. and Valentini, R. (eds). Africa and the carbon cycle: proceedings of the Open Science Conference on Africa and the Carbon Cycle: the CarboAfrica Project. Accra (Ghana) 25-27 November 2008. FAO, Rome. World Soil Resources Report, 105: 63-72pp.

Bonsu, M. & Laryea, K.B. (1989). Scaling the saturated hydraulic conductivity of an alfisol. J. Soil Sci. 40: 731-742.

Bonsu, M. & Laryea, K.B. (1989). Scaling the saturated hydraulic conductivity of an alfisol. J. Soil Sci. 40: 731-742.

Bremner, J.M. & Mulvaney, C.S. (1982). Nitogen-Total. In A.L. Page, R.H. Miller and D.R. Keeney(eds). Methods of Soil Analysis Part 2, Agronomy 9,595-624.

Brookes, P.C., Powlson, D.S. & Jenkinson, D.S. (1982). Measurement of microbial biomass phosphorus in soil. Soil Biology and Biochemistry 14: 319- 329.

Brookes, P.C., Powlson, D.S. & Jenkinson, D.S. (1982). Measurement of microbial biomass phosphorus in soil. Soil Biology and Biochemistry, 14: 319-329.

Bruzzone, B. (2020). The Report: Ghana 2020, Agriculture https://oxfordbusinessgroup.com/ghana-2020/agriculture 13/05/2021

Buckman, H.O. & Brady, N.C., (1970). The nature and properties of soils: London, The Macmillan Company, pp.653.

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E. & Brussaard, L. (2018). Soil quality-A critical review. Soil Biol. Biochem. 2018, 120, 105–125.

Byerlee, D., Stevenson, J. & Villoria, N. (2014). Does intensification slow crop land expansion or encourage deforestation? Glob. Food Secur. 3, 92–98.

Campbell, C. A., Biederbeck, V. O., Zentner, R. P. & Lafond, G. P. (1991). Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin black chernozem. Canadian Journal of Soil Science 71: 363- 376.

Canadell, J. G., Kirscbaum, M., Kurz, W. A., Sanz, M. J., Schlamadinger, B. & Yamagatta, Y. (2007). Factoring out natural and indirect human effects on terrestrial C sources and sinks. Environmental Science and Policy. 10:370-384.

Carter, M. R., Sanderson, J. B., Ivany, J. A. & White, R. P. (2002). Influence of rotation and tillage on forage maize productivity, weed species, and soil quality of a fine sandy loam in the cool-humid climate of Atlantic Canada. Soil Till. Res. 67, 85–98.

Chapman, N. O. and Pratt, P. (1961). Methods of Analysis for Soils, Plants and Water. University of California. pp .1-5.

Chen, G. X., Yu, K.W., Liao, L. P. & Xu, G. S. (2000). Effect of human activities on forest ecosystem: N cycle and soil fertility. Nutrient Cycling in Agroecosystems, 57: 45-54.

Chen, H. Q., Marhan, S., Billen, N. & Stahr, K. (2009). Soil organic-carbon and total nitrogen stocks as affected by different land uses in Baden-Wurttemberg (southwest Germany). J. Plant Nutr. Soil Sci. 172, 32–42.

Chen, T. H., Chiu, C. Y. & Tian, G. L. (2005). Seasonal dynamics of soil microbial biomass in coastal sand dune forest. Pedobiologia 49, 645-653.

Chesworth, W. (2008). Encyclopedia of soil science. The Netherlands: Springer, Dordrecht, 2008.

Chivandi, E., Mukonowenzou, N., Nyakudya, T. & Erlwanger, K. H. (2015). Potential of indigenous fruit-bearing trees to curb malnutrition, improve household food security, income and community health in Sub-Saharan Africa: A review. Food Res. Int. 76, 980–985.

Conant, R. T., Dalla-Betta, P., Klopatek, C. C., Klpatek, J. M. (2004). Controls on soil respiration in semiarid soils. Soil Biology and Biochemistry. 36(6):945-951.

Crave, A. & Gascuel-Odoux, C. (1997). The influence of topography on time and space distribution of soil surface water content. Hydrol. Processes, 11: 203–210.

Cubasch, U., Wuebbles, D., Chen, D., Facchini, M. C., Frame, D., Mahowald, N. & Winther, J. G. (2013). Introduction. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Daljit, S. K. S., Arifin, A., Radziah, O., Shamshuddin, J., Hazandy, A. H., Majid, N. M., Aiza-Shaliha, J., Rui, T. X., Keeren, S. R. (2013). Status of soil microbial population, enzymatic activity and biomass of selected natural, secondary and rehabilitated forests. American Journal of Environmental Science, 9(4): 301-309.

Daouda, B. O., Aliou, S., Léonard, A. E., Yasmine, A. J. F., Vincent, E. A., Irénikatché, A.P.B., Nestor, A. (2017). Assessment of organic carbon stock in cashew plantations (Anacardium occidentale L.) in Benin (West Africa). International Journal of Agriculture and Environmental Research ISSN: 2455-6939Volume:03, Issue:04 "July-August 2017.

Dawoe, E. (2009). Conversion of natural forest to cocoa agroforest in lowland humid Ghana: Impact on plant biomass production, organic carbon and nutrient dynamics. (PhD Thesis). Department of Agroforestry, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology.

Del-Grosso, S. J., Haw-Orson, A. D. & Parton, W. J. (2008). Testing DAYCENT model stimulations of corn yield and nitrous oxide emissions in irrigated tillage system in Colorado. Journal of Environmental Quality, 37: 1363-1389.

Dendena, B. & Corsi, S. (2014). Cashew, from seed to market: A review Article *in* Agronomy for Sustainable Development · Agron. Sustain. Dev. (2014) 34:753–772 DOI: 10.1007/s13593-014-0240-7.

Deng, L., Wang, K. B., Li, J. P., Zhao, G. W. & Shangguan, Z. P. (2016). Effect of soil moisture and atmospheric humidity on both plant productivity and diversity of native grasslands across the Loess Plateau, China. Ecol. Eng. 2016, 94, 525–531.

Devendra, C. (2012). Climate change threats and effects: challenges for agriculture and food security. Academy of Sciences Malaysia Series on Climate Change ISBN 978-983-9445-82-4 902-4. Jalan Tun Ismail, 50480 Kuala Lumpur.

Di, H. J., Cameron, K. C. & Shen, J. (2013). The role of bacteria and archaea in nitrification, nitrate leaching and nitrous oxide emissions in nitrogen-rich grassland soils, in Molecular Environmental Soil Science, Xu and D. L. Sparks, Eds., pp. 79–89, Springer, Dordrecht, Netherlands.

Djagbletey, E. D. (2017). Carbon stocks and soil nutrients characteristics of selected forest reserves in the Guinea Savanna Agroecological Zone of Ghana. [PhD thesis)] Kwame Nkrumah University of Science and Technology, Ghana.

Donovan, P. (2013). Measuring soil carbon change: A flexible, practical, local method. pp 1-56.

Doran, J. W. & Zeiss, M. R. (2000). Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15, 3–11.

Dowuona, G. N. N. & Adjetey, E. T. (2010). Assessment of carbon storage in some savanna soils under different land use systems in Ghana. ICID+18, August 16-20, Fortaleza - Ceará, Brazil.

Dunne, T. & Leopold, L. (1978). Water in Environmental Planning, Freeman, San Francisco.

Durot, C. (2013). Evaluation et comparaison des stocks de carbone des systèmes agroforestiers à base de cacaoyer du Centre Cameroun: Cas de l'arrondissement de Bokito. Mémoire de Master, groupe ISA Lille, France. 83 p. dynamics in sub-saharan Africa- Case study of Western Africa – Ghana. *Geophysical Research.*Ecology 47(1): 63-70.

Fageria, N. K., Baligar, V. C. & Jones, C.A. (2010). Growth and Mineral Nutrition of Field Crops, 3rd ed. CRC Press.

FAO (2003). Optimizing soil moisture for plant production. The significance of soil porosity. FAO Soils Bulletin 79 ISBN 92-5-104944-0 ISSN 0253-2050.

FAO (2004). Carbon sequestration in dry land soils. Smallholder farmers weeding in a woodlot. Malawi. World Soils Resources Reports 102. FAO/17754/A.

FAO (2008). FAOSTAT Online database. FAO-UN. Accessed March, 2018.http://faostat.fao.org.

FAO. (2010). Global forest resources assessment 2010, Main report, FAO Forestry Paper 163. Rome,Italy.

FAO (2011). FAOSTAT. Land-Use Statistics. Food and Agricultural Organization, Rome, Italy.

FAO (2012). Global forest land use changes 1990-2005, FAO forestry paper 169. Rome ISBN 978-92-5-107399-5 ISSN 0258-6150.

FAO (2013) http://faostat3.fao.org/faostat-gateway/go/to/browse/Q/QC/E. Accessed on 8 March 2017.

FAO (2015). Base des données de la FAO 2011. http://faostat3.fao.org. 26/05/2020

FAO and ITPS (2015). Status of the World's Soil Resources, Rome: s.n.

FAO. (2016). Food and Agricultural Organization of the United Nations Statistics Division. Available online: http://faostat3.fao.org/download/Q/QC/E (accessed on 10 March 2020).

FAO. (2019). *Major tropical fruits - Statistical compendium 2018*. Rome.

FAO.(2020). FAO publications catalogue 2020: October. Rome. https://doi.org/10.4060/cb1512en.

FAOSTAT (2017): Statistical Database. http://www.fao.org/faostat/en/ #data/QC. 07/10/2018.

FAOSTAT, (2016). Database Collections. Food and Agriculture Organization of the United Nations (FAO). http://faostat.fao.org. (Accessed, 9 march 2018).

Fatubarin, A. & Olojugba, M. R. (2014). Effect of Rainfall season on the chemical properties of the soil of a Southern Guinea Savanna Ecosystem in Nigeria. Journal of Ecology and the Natural Environment; 6(4): 182-189.

Feltrin, R. M., Paiva, J. B. D., Paiva, E. M. C. D., Sari, V. & Brites, L. S. (2013). Seasonal Variation in Soil Water Content for Forest and Pasture in Southern Brazil Vol. 56(6):1365-1370 © 2013 American Society of Agricultural and Biological Engineers ISSN 2151-0032 DOI 10.13031/trans.56.9960495.

Fitzpatrick, J. (2011). Cashew nut processing equipment study—summary. African Cashew initiative. http://www.africancashewalliance.com/sites/default/files/documents/ equipment study ab pdf final 13 9 2011.pdf. Accessed on 13 June 2018.

Gabarron-Galeote, M. A., Trigalet, S. & van Wesemael, B. (2015). Effect of land abandonment on soil organic carbon fractions along a Mediterranean precipitation gradient. Geoderma. 249–250:69-78.

Gebeyehu, G., Soromessa, T., Bekele, T., Teketay, D. (2019). Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern.

Ghana Forest Plantation Strategy (2016). Ghana forest plantation strategy :2016-2040. Forestry commission, Ghana.

Ghana Statistical Service GSS (2019). Ghana Living Standard Survey. www.stastsghana.gov.gh 21/12/2020

Gockowski J, Sonwa D. (2011). Cocoa intensification scenarios and their predicted impact on CO2 emissions, biodiversity conservation, and rural livelihoods in the Guinea Rain Forest of West Africa. Environ Manage. 2011;48(2):307–21.

Gol, C. (2009). The effects of land use change on soil properties and organic carbon at Dagdami river catchment in Turkey. Journal of Environmental Biology, vol. 30, no. 5, pp. 825–830.

Gol, C. & Dengiz, O. (2008). Effect of modifying land cover and long-term agricultural practices on the soil characteristics in native forest-land. Journal of Environmental Biology, 29(5): 677-82.

Groffman, P. M., McDowell, W. H., Myers, J. C. & Merriam, J. L. (2001). Soil microbial biomass and activity in tropical riparian forests. Soil Biology & Biochemistry 33, 1339-1348.

Grossman, J. M. (2003). Exploring farmer knowledge of soil processes in organic coffee system of Chiapas, Mexico. Geoderma, Vol. 111, pp 267- 287.

Grumiller, Jan *et al*. (2018): Strategies for sustainable upgrading in global value chains: The Ivorian and Ghanaian mango sectors, ÖFSE Policy Note, No. 25/2018, Austrian Foundation for Development Research (ÖFSE), Vienna. http://hdl.handle.net/10419/184688 14/02/2020

Guilser, C. (2006). Effect of forage cropping treatment on soil structure and relationship with fracta dimensions. Geoderma, vol. 131, no. 1-2, pp. 33–44.

Guimarães, D. V., Gonzaga, M. I. S., da Silva, T. O., Silva, T. L., Dias, N. S. & Matias, M. I. S. (2013). Soil organic matter pools and carbon fractions in soil under different land uses. Soil Till Res. 126:177-182.

Gupta, N., Rudra, R. P. & Parkin, G. (2006). Analysis of spatial variability of hydraulic conductivity at field scale. Can. Biosyst. Engng., 48: 1.55- 1.62.

Haripal, K. & Sahoo, S. (2014). Microbial biomass carbon, nitrogen, and phosphorus dynamics along a chrono sequence of abandoned tropical agroecosystems. International Journal of Current Microbiological Applications and Science, 3(9): 956-970.

Hassink, J. (2016). The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant and Soil.191:77-87.

He, H., Liu, Y., Hu, Y., Zhang, M., Guodong Wang, G. & Shen, W. (2020). Soil microbial community and its interaction with soil carbon dynamics following a wetland drying process in Mu us sandy land. International Journal of Environmental Research and. Public Health 17, 4199; doi:10.3390/ijerph17124199.

Henrot, J. & Robertson, G.P. (1994). Vegetation removal in two soils of the humid tropics: Effect on microbial biomass. Soil Biology and Biochemistry. 1994;26(1):

Hernandez, D. L. & Hobbie, S. E. (2010). The effects of substrate composition, quantity and diversity on microbial activity. Plant and Soil. 335: 397-411.

Hillel, D. (1982). Introduction to soil physics. Academic Press, Inc. San Diego, California.

Hillel, D. (1998). Environmental Soil Physics. Academic Press. San Diego, CA.

Horel, A., Tóth, E., Gelybó, G., Kása, I., Bakacsi, Z. & Csilla Farkas, C. (2015). Effects of Land Use and Management on Soil Hydraulic Properties Open Geosci.; 1:742–754 DOI 10.1515/geo-2015-0053.

Hoyle F. C, Murphy D. V. and Fillery I. R. P. (2006). Temperature and stubble management influence microbial CO_2-C evolution and gross transformation rates, Soil Biology and Biochemistry 38: 71-80.

He, H., Liu, Y., Hu, Y., Zhang, M., Wang, G. & Weibo, S. (2020). Soil Microbial Community and Its Interaction with Soil Carbon Dynamics Following a Wetland Drying Process in Mu Us Sandy Land. Int. J. Environ. Res. Public Health 2020, 17, 4199; doi:10.3390/ijerph17124199

Huang, Z., Wan, X., He, Z., Yu, Z., Wang, M. & Hu, Z. (2013). Soil microbial biomass, community composition and soil nitrogen cycling in relation to tree species in subtropical China. Soil Biol Biochem. 62: 68±75.

IPCC, (2001). Climate change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, UK. 1000 p.

IPCC (Intergovernmental Panel on Climate Change), (2003). Good Practice Guidance for Land Use, Land-use Change and Forestry (LULUCF). Institute for Global Environmental Strategies, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC) (2014). Fifth Assessment Synthesis Report. 2014. Climate Change 2014 –Synthesis report.

International Coffee Organization ICO (2018). Country Coffee Profile: Ghana. International Coffee Council 122nd Session 17 – 21 September 2018 London, United Kingdom

Iqbal, J., Thomasson, J. A., Jenkins, J. N., Owen, P. R. & Whistler, F. D. (2005). Spatial variability analysis of soil physical properties of alluvial soils. Soil Sci. Soc. Am. J., 69: 1338–1350.

Isaac, M. E., Gordon, A. M., Thevathasan, N., Oppong, S. K. and Quashie-Sam, S. J. (2005). Temporal changes in soil carbon and nitrogen in West African multi-strata agroforestry systems: a chronosequence of pools and fluxes. Agroforestry Systems 65:23–31.

James, J. & Harrison, R. (2016). The effect of harvest on forest soil carbon: A meta-

Jayathilaka, P. M. S., Soni, P., Perret, S., Jayasuriya, H. P. W. & Salokhe, V. M. (2012). Spatial assessment of climate change effects on crop suitability for major plantation crops in Sri Lanka. Regional environmental change 1, 55-68.

Buyer, J. S., Baligar, V. C., He, Z. & Arévalo-Gardini, E. (2017). Soil microbial communities under cacao agroforestry and cover crop systems in Peru. Applied Soil Ecology 120 (2017) 273–280 http://dx.doi.org/10.1016/j.apsoil.2017.09.009.

Jenkinson, D.S. (1988). Determination of microbial biomass carbon and nitrogen in soil. In: Wilson, J.R. (ed.). Advances in Nitrogen Cycling in Agricultural Ecosystems. Pp. 368- 386. C.A.B. International, Wallingford.

Jenkinson, D. S. & Ladd. J. N. (1981) Microbial biomass in soil: Measurement and turnover. pp. 415-417. In: E.A. Paul & J.N. Ladd (eds.) Soil Biochemistry. Mercel Dekker, New York.

Jirka, S., McDonald, A. J., Johnson, M. S., Feldpausch, T. R., Couto, E. G., & Riha, S. J. (2007). Relationships between soil hydrology and forest structure and composition in the southern Brazilian Amazon. J. Veg. Sci., 18: 183-194, 2007 IAVS; Opulus Press Uppsala. John Wiley and Sons, UK, ISBN-13: 9780470209394.

Kahimba. F. C., Sri-Ranjan, R., Froese, J., Entz, M. & Nason, R. (2008). Cover crop effects on infiltration, soil temperature, and soil moisture distribution in the Canadian prairies. American Society of Agricultural and Biological Engineers Vol. 24(3): 321-333 ISSN 0883-8542.

Kara, O. & Bolat, I. (2009). Short-term effects of wildfire on microbial biomass and abundance in black pine plantation soils in Turkey. Ecol. Ind. 9, 1151–1155.

Karam, D.S., Arifin, A., Radziah, O., Shamshuddin, J., Abdul-Hamid, H., Majid, N.M., Zahari, I., Halim, N.H.A., Yen, C.K. (2013). Evaluation of soil biological properties of 9- and 15-year-old-stands in the oil palm plantation in Perak, Malaysia. African Journal of Agricultural Research, 8(29): 3904-3910.

Karlen, D. L., Hurley E. G. & Andrews S. S. (2006). Crop rotation effects on soil quality at three northern corn/soybean belt locations, Agronomy Journal, vol. 98, no. 3, pp. 484–492

Kell, D. B. (2011). Breeding crop plants with deep roots: their role in sustainable C, nutrient and water sequestration. Annals of Botany. 108:407-418.

Kemper, W. D. & Rosenau, R. C. (1986). Aggregate stability and size distribution. In: Klute, A. (Ed.); Methods of Soil Analysis, Part 1: Physical Analysis. Soil Sci. Soc. Am., Madison, WI, 425–442.

Khan, K. S. & Joergensen, R. G. (2012). Relationships between P fractions and the microbial biomass in soils under different land use management. Geoderma 173, 274–281. https://doi.org/10.1016/j.geoderma.2011.12.022.

Kiani, M. Hernandez-Ramirez, G. & Quideau, S., (2017). Quantifying sensitive soil quality indicators across contrasting long-term land management systems: crop rotations and nutrient regimes," Agriculture, Ecosystems & Environment, vol. 248, pp. 123–135, 2017.

Kishore, K. (2010). *Cocoa Production in Ghana.*

Klute, A. (1986). Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Second Edition. Am. Soc. Agron., Inc.

Klute, A. & Dirksen, C. (1986). Hydraulic conductivity and diffusivity. Laboratory methods. In: Klute, A. (Ed.); Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph 9. Am. Soc. Agron., Madison, WI. 2nd Edn.

Kolavalli, S. & Vigneri, M. (2011). Cocoa in Ghana: Shaping the success of an economy. In P. Chuhan-Pole and M. Angwafo (Eds.), Yes Africa can: Success stories from a dynamic continent (pp. 201-217).Washington, D.C.: World Bank.

Kone, A.W. . & Yao, M.K. (2021). Soil microbial functioning and organic carbon storage: can complex timber tree stands mimic natural forest? Journal of Environmental Management 283 (1-2):112002 DOI:1.11/j.jenvman.2021.112002

Kooch, Y. & Noghre, N. (2020). The effect of shrubland and grassland vegetation types on soil fauna and flora activities in a mountainous semi-arid landscape of Iran. Sci. Total Environ. 703, 1–9.

Kooch, Y., Moghimian, N. & Kolb, S. (2019). Microbial hotspot areas of C and N cycles in old-growth Hyrcanian forests top soils. For. Ecol. Manage. 446, 93–104.

Kooch,Y., Mehr, M.A. & Hosseini, S. M. (2020). The effect of forest degradation intensity on soil function indicators in northern Iran Ecological Indicators 114 106324 https://doi.org/10.1016/j.ecolind.2020.106324.

Koranda, M., Kaiser, C., Fuchslueger, L., Kitzler, B., Sessitsch, A., Zechmeister-Boltenstern, S. (2013). Seasonal variation in functional properties of microbial communities in beech forest soil. Soil Biol Biochem. 2013; 60: 95±104. https://doi.org/10.1016/j.soilbio.2013.01.025 PMID: 23645937.

Kurmia-nto, S. *et al*. (2019). The influence of land-cover changes on the variability of saturated hydraulic conductivity in tropical peat lands. Mitigation and Adaptation Strategies for Global Change, 24(4):535-555, 2019.

Kyere, K., Agyarko, K., Osei, B. Y. & Asiedu, E. K. (2018). Influence of Grass Mulch on Soil Physical Attributes of a Luvisol and Water Requirement of Cowpea (Vigna unguiculata) in the Transitional Zone of Ghana. Asian Soil Research Journal (ASRJ): Vol.:1, Issue: 2.DOI:10.9734/ASRJ/2018/41875

Kyrlund, B. (1990) The potential of forests and forest industry in reducing excess

Ladd, J.N. & Amato, M. (1989). Relationship between microbial biomass carbon in soils and absorbance of extracts of fumigated soils. Soil Biology and Biochemistry 21: 457- 59.

Laderach, P., Eitzinger, A., Martinez, A., and Castro, N. (2011). Predicting the impact of climate change on cashew growing regions in Ghana and Cote d'Ivoire, Final report September, 2011, International Center for Tropical Agriculture (CIAT).

Lal, R. & Follett, R.F. (2009). Soil Carbon Sequestration and the Green house Effect. 2nd ed. Madison, Wisconsin, USA: Soil Science Society of America, Inc.

Lal, R. (1994). Sustainable land use systems and soil resilience. In: Greenland D.J., Szabolcs I. (Eds.). Soil Resilience and Sustainable Land Use, CAB International, Wallingford, UK. pp 41-67.

Lal, R. (2002). Why carbon sequestration in agricultural soils. In: Kimble, J.M., Lal, R. Follett, R.F, editors. Agricultural Practices and Policies for Carbon Sequestration in Soil. Boca Raton: Lewis Publishers. pp. 21-30.

Lal, R. (2005). No-till farming and environment quality. Anais do Simpósio sobre Plantio Direto e Meio Ambiente: Sequestro de Carbono e Qualidade da Água, Foz do Iguaçu, p. 29-37.

Lal, R. 2007. C management in agricultural soils. Mitigation and Adaption Strategies for Global Change. 12:303-322.

Lal, R., Follett, R.F., Stewart, B.A. and Kimble, J.M. (2007). Soil carbon sequestration to mitigate climate change and advance food security. Soil Science 172, 943–956. doi:10.1097/ss.0b013e31815cc498.

Lambin, E. F., Geist, H. J. & Lepers, E. (2003). Dynamics of land-use and land-cover Change in tropical regions. Annu. Rev. Environ. Resour. 2003. 28:205–41doi: 10.1146/annurev.energy.28.050302.105459

Laurance, W. F., Sayer, J. & Cassman, K. G. (2014). Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol., 29, 107–116.

Leckie, S. E, Prescott, C. E. & Grayston, S. J. (2004). Forest floor microbial community response to tree species and fertilization of regenerating coniferous forests. Canadian Journal of Forest Research 34, 1426-1435.

Liebig, M. A., Tanaka, D. L., Wienhold, B. J. (2004). Tillage and cropping Seasonal changes of soil organic carbon and microbial biomass carbon in different forest. Soil & Tillage Research. 2004; 78:131-141. DOI: http://dx.doi.org/10.5772/intechopen.90656.

Lipiec, J., Kus, J., Slowinska-Jurkiewicz, A. & Nosalewicz, A. (2006). Soil porosity and water infiltration as influenced by tillage methods. Soil Till. Res., 89(2): 210–220.

Litton, C. M. & Santelices, R. (2002). Early post-fire succession in a Nothofagus glauca forest in the Coastal Cordillera of south-central Chile. International Journal of Wild land Fire; 11:115-125.

Liu, X., Herbert, S. J., Hashemi, A. M., Zhang, X. & Ding, G. (2006). Effects of agricultural management on soil organic matter and carbon transformation–a review, Plant, Soil and Environment, vol. 52, no. 12, pp. 531–543.

Liu, Y., Wang, S., Wang, Z., Zhang, Z., Qin, H., Wei, Z., Feng, K., Li, S., Wu, Y., Yin, H., Li, H. & Deng, Y. (2019). Soil micro biome mediated nutrients decline during forest degradation process. Soil Ecol. Lett. 1 (1–2), 59–71.

Lobell, D.B. & Gourdji, S.M. (2012). Climate Change and Global Crop Productivity. American Society of Plant Biologists Vol. 160, pp. 1686–1697, www.plantphysiol.org/cgi/doi/10.1104/pp.112.208298

Lu, N., Liski, J., Chang, R. Y., Akujarvi, A., Wu, X., & Jin, T. T. (2013). Soil organic carbon dynamics of black locust plantations in the middle Loess Plateau area of China. Biogeosciences, 10, 7053–7063.

Maestre, F. T., Delgado-Baquerizo, M., Jeries, T. C., Eldridge, D. J. and Singh, B. K. (2015). Increasing aridity reduces soil microbial diversity and abundance in global drylands. Proc. Natl. Acad. Sci. USA 2015, 112, 15684–15689.

Magdoff, F. & Weil, R. R. (2004). Soil Organic Matter in Sustainable Agriculture. CRC Press, Boca Raton, London, New York Washington DC. pp 1-35.

Mampong Metrological Station (2018)

Manlay, R. J., Masse, D., Chevallier, T., Smith, A.R., Friot, D., Feller, C. (2004). Post fallow decomposition of woody roots in the Western African Savanna. Plant Soil, 260: 123-136.

Manzoni, S., Schimel, J.P. & Porporato, A. (2012) A. Physical vs. physiological controls on water-stress response in soil microbial communities. Ecology 2012, 93, 930–938.

Marafa, L. M. & Chau, K. C. (1999). Morphological and chemical properties of soils along a vegetation gradient affected by fire in Hong Kong. Soil Science, 164: 683-691.

Marinari, S, Mancinelli, R, Campiglia, E and Grego, S. (2006). Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecological Indicators. 6(4):701-711.

Mayer.M., Prescottc, C. E., Abakerd, W. E. A., Augustoe, L., Cécillonf, L., Ferreirah, G. W. B., Jamesi, J., Jandlj. R., Katzensteinera, K., Laclauk, J-P., Laganièrem, J., Nouvellonk, Y., Parém, D., Stanturfn, J.A., Vanguelovao, E.I. & Vesterdalp, L (2020). Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis Forest Ecology and Management 466 118127, journal homepage: www.elsevier.com/locate/foreco.

McCarthy, H. R., Oren, R., Johnsen. K.H, *et al.* (2010). Re-assessment of plant carbon dynamics at the Duke free-air CO2 enrichment site: interactions of atmospheric [CO_2] with nitrogen and water availability over stand development. New Phytologist, 185, 514-528.

McGonigle, T. P. and Turner, W. G. (2017). Grasslands and croplands have different microbial biomass carbon levels per unit of soil organic carbon. Agriculture 7, 57. https://doi.org/10.3390/agriculture7070057.

McGrath, D.A., Smith, C.K., Gholz, H.L. and de Assis Oliveira, F. (2001). Effects of land-use change on soil nutrient dynamics in Amazonia. Ecosystems, 4(7): 625-645.

McLaughlin, M. J. & A. M. Alston. (1986). The relative contribution of plant residues and fertilizer to the phosphorus nutrition of wheat in a pasture/cereal system. Australian J. Soil Research 24:517-26.

Melenya, C., Bonsu, M., Logah, V., Quansah, C., Adjei-Gyapong, T., Yeboah, I. B., Tuffour, H. O., Abubakari, A. (2015). Carbon sequestration in soils under different land use systems and its impact on climate change. Applied Research Journal Vol.1, Issue, 3, pp.164-168, ISSN: 2423-4796.

Merrill, S. D., Tanaka, D. L., Krupinsky, J. M., Liebig, M. A. & Hanson J. D. (2007). Soil water depletion and recharge under ten crop species and applications to the principles of dynamic cropping systems, Agron. J., 99, 931–938.

Mhawish, Y., M. (2015). Effect of land-use/cover change on physical and chemical soil properties within an agricultural ecosystem of Ajloun Area-Jordan. International Journal of Geology, Earth & Environmental, 5 (2): 1-17.

Ministry of Food and Agriculture, (2013) Agriculture in Ghana: facts and figures. By the Statistics, Research and Information Directorate. Accra.

MOAP (2016): Post-harvest losses in the mango, pineapple and citrus value

MOFA (2020) MEDIUM TERM EXPENDITURE FRAMEWORK (MTEF) FOR 2020-2023 pg 6-8

Monteiro, F., Catarino, L., Batista, D., Indjai, B., Duarte, M.C D., Romeiras, M .M. (2017). Cashew as a High Agricultural Commodity in West Africa: Insights towards Sustainable Production in Guinea-Bissau. Sustainability, 9, 1666 doi:10.3390/su9091666.

Moore, I. D. (1981). Effects of surface sealing on infiltration. Transactions of American Society of Agricultural Engineers, 24: 1546-1552.

Morel, C., Tiessen, H. and Stewart, J.W.B. (1997). Correction for P- sorption in the measurement of soil microbial biomass P by chloroform fumigation. Soil Biology and Biochemistry 29:1579-1583.

Mossu, G. (1992). The Tropical Agriculturist. Macmillian Press Ltd, London, UK ISBN: 9780333570760 Cocoa. 1992 pp.vi+130 pp. ref.9

Muñoz-Rojas, M., Jordán, A., Zavala, L., De la Rosa, D., Abd-Elmabod, S. K. & Anaya-Romero, M. (2015). Impact of land use and land cover changes on organic carbon stocks in Mediterranean soils (1956-2007). Land Degrad Dev: 26:168-179.

Naik, S. K., Maurya, S. Bhatt, B. P. (2016). Soil organic carbon stocks and fractions in different orchards of eastern plateau and hill region of India Agroforest Syst 2016 DOI 10.1007/s10457-016-9957-4.

Nair, P. K. R., Kumar, B. M. & Nair, V. D. (2009). Agroforestry as a strategy for carbon sequestration. Journal of plant nutrition and soil science/ Volume 172, Issue 1 pg 10-23. https://doi.org/10.1002/jpln.200800030

Nair, P. K. R. & Nair, V.D (2014). 'Solid-fluid-gas': the state of knowledge on carbon sequestration potential of agroforestry in Africa. Current Opinion in Environmental Sustainability. Volume 6, Pg 22-27. https://doi.org/10.1016/j.cosust.2013.07.014

Nanganoa, L. T., Okolle, J. Missi, N. V., Tueche, J. R., Levai, L. D., Njukeng, J. N. (2019). Impact of Different Land-Use Systems on Soil Physicochemical Properties and Macrofauna Abundance in the Humid Tropics of Cameroon. Applied and Environmental Soil Science Volume 2019, Article ID 5701278, 9 pages https://doi.org/10.1155//5701278.

Nave, L., DeLyser, K., Butler-Leopold, P., Sprague, E., Daly, J. & Swanston, C. (2019). Effects of land use and forest management on soil carbon in the ecoregions of Maryland and adjacent eastern United States. For. Ecol. Manage. 448, 34–47.

Nelson, D. W. and Sommer, L. E. (1982). Total carbon, organic carbon, and organic matter. 539-579 p. In: A.L. Page (ed.) Methods of Soil Analysis. 2nd Ed. ASA Monogr. 9(2). American Society Agronomy, Madison, WI.

Njar, G. N., Iwara, A. I., Ekukinam, U. E., Deekor, T. N. & Amiolemen, S.O. (2011). Organic Carbon and Total nitrogen status of soils under rubber plantation of various ages, South-South Nigeria. Journal of Environmental Sciences and Resource Management, 3: 1- 13.

National Land and Water Resource audit, NLWRA (2008). Soil Conditions - Status of information for reporting against indicators under notational natural resource management monitoring and evaluation framework. Publisher: National Land & Water Resources Audit (NLWRA), Braddon, Australia. ISBN: 978 0 642 37157 7.

NurQursyna Bt BC, Adzmi BY, Rashid BA.(2013) Mornitoring the effect of precipitation and pineapple cultivation on the dynamics of nutrient and chemical properties in peat in peat soils. Jor. Life Sci. and Tech. 2013; 1(4):238-245.

Oberson, A., Friesen, D.K., Morel, C. & Tiessen. H. (1997). Determination of phosphorus released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. Soil Biology and Biochemistry 299: 1577- 1583.

Oduro K. A. *et al.*, (2012). Ghana Forest and Wildlife Handbook, Ghana Forest and Wildlife Resources, 2012: A compendium of information about forests and wildlife resources, forestry related issues and wood processing in Ghana. Ghana Forest Plantation Strategy: 2016-2040 June, 2016 Mlnr 2016.

Ogeh, J. S. & Ipinmoroti, R. R. (2015). Soil Organic Carbon Dynamics under different plantation crops of different ages in a Tropical Oxic Paleustalf, University of Mauritius Research Journal – Volume 21.

Ogunkunle, C. O. & Awotoye, O. O. (2011). Soil fertility under different tree cropping system in a Southwestern zone of Nigeria. Not. Sci. Biol., v. 3, p. 123-128.

Oke, D. & Olatiilu, A. (2011). Carbon storage in agroecosystems: a case study of the cocoa based agroforestry in Ogbese forest reserve, Ekiti State, Nigeria. J Environ Prot. 2011;2 (8):1069–75.

Oladele, S. O. & Adeyemo, A, J. (2016). Land use influences microbial biomass carbon, organic carbon and nitrogen stock in a tropical acric luvisols of Southwestern Nigeria. Brazilian Journal of Biological Sciences. v. 3, no. 6, p. 413-423. ISSN 2358-2731 http://dx.doi.org/10.21472/bjbs.030617.

Olojugba, M. R. (2018). Effects of Rainfall Seasonal Dynamics on the Chemical Properties of the Soil of a Tropical Southern Humid Rainforest Ecosystem in Nigeria International Journal of Plant & Soil Science 23(5): 1-11; Article no.IJPSS.17122 ISSN: 2320-7035.

Olsen, S. R. & Sommers, L. E. (1982). Phosphorus. In A. L. Page *et al*., (ed.) Methods of soil analysis, 2nd ed. Agronomy, 9:403-430.org/uploadedFiles/intracenorg/Content/About_ITC/Where_are_we_working/Multi-country_programmes/Pact_II/National%20mango%20study%20-%20 Ghana. pdf . (3/03/2018)

Osakwe, U. C. & Igwe, C. A. (2013). Conversion of forests to arable land and its effect on soil physical properties in Enugu State South Eastern Nigeria. Nigerian Journal of Biotechnology, vol. 26, pp. 33–40.

Osei, B. Y., Agyarko, K., Kyere, K. & Asiedu, E. K. (2017). Response of hydro-physical properties of a Chromic Luvisol in Ghana to different methods of application of Mucuna pruriens as a soil. International Journal of Environment, Agriculture and Biotechnology (IJEAB): Vol- 2, Issue-5 ,2559-2568. http://dx.doi.org/10.22161/ijeab/2.5.37

Osei, B. Y., Agyiri M., Asiedu, E. K. & Agyarko, K. (2017). Assessment of the Relative Suitability of Three Different Soils for Dry Season Lettuce Production in Ghana. International Journal of Environment, Agriculture and Biotechnology (IJEAB): Vol-2, Issue-5, 2546-2553. http://dx.doi.org/10.22161/ijeab/2.5.35

Osei, B.Y., Agyarko, K., Asiedu, E. K., Agyiri, M., Kyere, K., Amponsah, E. K., Atakora, K. (2018). Influence of Different Soil Application Methods of Mucuna puriens on Soil Chemical Properties and Maize Yield in Ghana. International Journal of Plant & Soil Science 24(6): 1-9, 2018; ISSN: 2320-7035 DOI:10.9734/IJPSS/2018/43186.

OSUN, T. (2001). Analysis of Socio-Economic Factors Affecting Cocoa Production in Ondo State: Case Study of Idanre and Ondo East Local Government Areas. B. Sc Thesis in the Department of Agricultural Economics and Extension, federal University of Technology, Akure, Nigeria.

Pabst, H., Gerschlauer, F., Kiese, R. & Kuzyakov, Y. (2016). Land use and precipitation affect organic and microbial carbon stocks and the specific metabolic quotient in soils of eleven ecosystems of Mt. Kilimanjaro, Tanzania. Land Degrad. Dev. 27, 592–602.

Pacala, S. & Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science 05:968-971.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., Hayes, D., (2011). A large and persistent carbon sink in the world's forests. Science 333, 988–993.

Panda, T., Pani, P. K. & Mohanty, R. B. (2010). Litter decomposition dynamics associated with cashew nut plantation in coastal habitat of Orissa, India. Journal of Oceanography and Marine Science Vol. 1(4), pp. 79-85, ISSN 2141-2294.

Pankhurst, C. E, Kirkby, C. A., Hawke, B. G. & Harch B. D. (2002). Impact of change in tillage and crop residue management practice on soil chemical and microbiological properties in a cereal-producing red duplex soil in NSW, Australia. Biological Fertility of Soils 35:189-196.

Parsapour, M. K., Kooch, Y., Hosseini, S. M. & Alavi, S .J. (2018). C and N cycle monitoring under Quercus castaneifolia plantation. For. Ecol. Manage. 427, 26–36.

Pattanayak, S. & Mercer, D. E. (1996). Valuing soil conservation benefits of agroforestry practices. Southeastern Center for Forest Economics Research, Research Triangle Park, NC. FPEI Working Paper No. 59. 21 p.

Pearson, P. N. & Palmer, M. R. (2000). Atmospheric Carbon dioxide concentrations over the past 60 million years. Nature. 406(6797):695-699.

Peichl, M., Thevathasan, N. V., Gordon, A. M., Huss, J. & Abohassan, R. A. (2006). Carbon Sequestration Potentials in Temperate Tree-Based Intercropping Systems, Southern Ontario, Canada. Agroforestry Systems, 66, 243-257.

Penn State Extension (2008). The role of trees and forests in healthy watersheds managing stormwater, reducing flooding, and improving water quality. Forest Stewardship Bulletin #10.

Philip, J. R. (1957). The theory of infiltration, 4, Sorptivity and algebraic infiltration equations, Soil Sci., 84: 257–264.

Pinto, L. C., Avila, L. F. & Mello, C. R. (2017). Land-use effect on hydropedology in a mountainous region of Southeastern Brazil. Ciência e Agroteconologia, 41(4):413-427.

Pinto, L.C., Mello, C.R., Norton, L.D. & Curi, N. (2019). Land-use influence on the soil hydrology: An approach in upper Grande River basin, Southeast Brazil Ciência e Agrotecnologia,(Science And Agrotechnology) 43:e015619, Agricultural Sciences eISSN 1981-1829 http://dx.doi.org/10.1590/1413-7054201943015619.

Poeplau, C. & Don, A. (2013). Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma 192, 189–201. https://doi.org/10.1016/j.geoderma.

Powlson, D. S., Whitmore, A. P. & Goulding, K. W. T. (2011). Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false. European Journal of Soil Science, 62, 42-55.

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A.P., Hirsch, P.R. & Goulding, K.W.T. (2011a). Soil management in relation to sustainable agriculture and ecosystem services. Food Policy 36, S72–S87.

Ralph, K. (2013). Record 400ppm CO_2 milestone feels like we're moving into another era. Guardian Environment Network. 15p.

Ranger, J., Gérard, F., Lindemann, M., Gelhaye, D. & Gelhaye, L. (2003). Dynamics of litter fall in a chronosequence of Douglas fir (Pseudotsuga menziesii) stands in the Beaujolais mounts (France), Annals of Forest Science 60:475–488.

Rawls, W. J., Ahuja, L. R., Brakensiek, D. L. & Shirmohammadi, A. (1993). Infiltration and soil water movement. In: Handbook of Hydrology. McGrawHill, Inc.

Reichstein, M. (2007). Impacts of climate change on forest soil carbon: principles, factors, models, uncertainties. Forestry and climate change. 10, 127-135. relation to land-use in subtropical systems of north-east India. Tropical

Reubens, B., Poesen, J., Danjon, F., Geudens, G. & Muys, B. (2007). The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review, Trees, 21, 385–402.

Rogéria. P., Rafael. V., Eduardo. C., Ricardo. F. & Joaquim Albenísio, G. (2005). Photosynthetic responses of young cashew plants to vary in environmental conditions. Pesquisa Agropecuária Brasileira. Brasília, v.40, n.8, p.735-744.

Rose, D. A., Lal, R. & Shukla, M. K. (2005). Principles of Soil Physics. Marcel Dekker, New York, 2005.

Ross, D. J. & Tate, K. R. (1993). Microbial C and N in litter and soil of a southern beech Nothofagus forest: Comparison of measurement procedures. Soil Biology and Biochemistry, 25: 467-475.

Ross, D. J. & Tate, K. R. (1993). Microbial carbon and nitrogen, and respiratory activity, in litter and soil of southern beech (Nothofagus) forest distribution and properties. Soil Biology and Biochemistry 25: 477- 483.

Rupa, T. R., Rejani, R. & Bhat, G. M. (2013). Impact of Climate Change on Cashew and Adaptation Strategies. Climate-Resilient Horticulture: Adaptation and Mitigation Strategies. 9, 78-91, Springer India.

Salam, M. A. &Peter, K. V. (2010). Cashew-A Monograph; Studium Press (India) Pvt. Ltd.: New Delhi, India. Rabany, C., Rullier, N.; Ricau, P. The African Cashew Sector in 2015. Availableonline:http://www.rongead.org/IMG/pdf/african_cashew_market_review_rongead_ica2015.pdf (accessed on17 May 2020).

Salvador, M. M. S., Libardi, P. L., Brito, A. S. & Moreira, N. B. (2012). Estabilidade temporal e variabilidade espacial da distribuição da armazenagem de água no solo numa sucessão feijão/aveia-preta. Revista Brasileira de Ciência do Solo 36(5): 1434-1447.

Sarjubala, A. D. & Yadava, P. S. (2007). Wood and leaf litter decomposition of Dipterocarpus tuberculatus Roxb. in a tropical deciduous forest of Manipur, North East India. Curr. Sci., 93(2): 243-246.

Scharlemann, J. P. W., Tanner, E. V. J., Hiederer, R. & Kapos, V. (2014). Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Manage. 5, 81–91.

Schembre, C. (2009). Soil types and fundamental soil properties of a Costa Rican tropical Montane Cloud Forest. Reserva Cloudbridge San Gerardo de Rivas, Cordillera de Talamancas.

Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T, Guggenberger, G. & Janssens, I, A. (2011). Persistence of soil organic matter as an ecosystem property. Nature; 478:4956.

Silva, D. C., Silva, M.L.N., Curi, N., Oliveira, A.H., Souza, F.S., Martins, S.G. and Macedo, R.L.G. (2011). Soil attributes in agroforestry systems, conventional and native forest. Review of Environmental Studies, 13: 77-86.

Singh, R. B. and Yadava, P. S. (2006) Spatial distribution of microbial biomass in

Singh, R.B. Shi, C. (2014). Advances in observation and estimation of land use impacts on climate changes: improved data, upgraded models, and case studies, Adv. Met. 2014, 1–7.

Six, J., Frey, S.D., Thiet, R. K. and Batten, K. M. (2006). Bacterial and fungal contributions to carbon sequestration in agroecosystems. Soil Sci. Soc. Am. J., 70, 555–569.

Skaggs, R. W. and Khaleel, R. (1982). Chapter 4: Infiltration. In: Hydrology of Small Watersheds. St Joseph, Michigan, American Society of Agricultural Engineers.

Sloan, S. & Sayer, J. A. (2015). Forest resources assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. For. Ecol. Manage. 352, 134–145.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H. H., Kumar, P, McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, R. J., Sirotenko. O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider U, Towprayoon, S., Wattenbach, M. & Smith, J.U. (2008). Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society 363, 789–813. doi:10.1098/rstb.2007. 2184.

Smith, V.C. & Bradford, M.A. (2003). Litter quality impacts on grassland decomposition are differently dependent on soil fauna across time. Applied Soil Ecol., 24: 197-203.

Soil Science Society of America (1975). Glossary of soil science terms: Madison, Wisconsin, Soil Science Society of America.

Soil Science Society of Ghana (2009) *Guide to Interpretation of Soil Analytical Data.*

Sparling, G.P. (1992). Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Australian Journal of Soil Research 30, 195-207.

Sparling, G.P. (1992). Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Australian Journal of Soil Research: 30, 195-207.

Sparling, G. P. (1997). Soil microbial biomass, activity and nutrient cycling as indicators of soil health. In: Pankhurst C, Doube BM, Gupta VVSR, editors. Biological Indicators of Soil Health. Wallingford: CAB International. pp. 97-119.

Sparling, G. P. & West, A. W. (1998). A direct extraction method to estimate soil microbial carbon: Calibration in situ using microbial respiration and ^{14}C-labelled cells. Soil Biology and Biochemistry, 20: 337-43.

Sparling, G. P., Feltham, C. W., Reynolds, J., West, A. W. and Singelton, P. (1990). Estimation of soil biomass C by a fumigation–extraction method: use on soils of high organic matter content, and reassessment of the kEC-factor. Soil Biology and Biochemistry, 22: 301-307.

Styles, D. & Coxon, C. (2007). Meteorological and management influences on seasonal variations in phosphorous fractions extracted from soils in western Ireland, Geoderma;142:52-164.

Tandjiékpon, A. (2010). Caractérisation du système Agroforestiers à base d’anacardier (Anacardium Occidentale linnaeus) en zone de Savane au Benin. Mémoire présenté à la Faculté des Lettres Arts et Sciences Humaines pour l'obtention du grade de Diplôme d’Etudes Approfondies (DEA). 122 p.

Tandjiékpon, A., Lagbadohossou, A., Hinvi, J. & Afonnon, E. (2003). La culture de l’anacardier au Bénin. Référenciel Technique. Edition INRAB, Bénin. 86p.

Terefe, H., Argaw, M., Tamene, L., Mekonnen, K., Recha, J. & Solomon, D. (2020). Effects of sustainable land management interventions on selected soil properties in Geda watershed, central highlands of Ethiopia. Ecol Process.9:14.

Tetteh, E. N. (2017) Rubber/Plantain Agroforestry: Potential for household food security in the rubber growing areas of Ghana. [PhD thesis] Kwame Nkrumah University of science and technology, Faculty of Renewable Natural Resources, College of Agriculture and Natural Resources

Tian, J., McCormack, L., Wang, J., Guo, D., Wang, Q., Zhang, X., Kuzyakov, Y. (2015). Linkages between the soil organic matter fractions and the microbial metabolic functional diversity within a broad-leaved Korean pine forest. Eur. J. Soil Biol. 66, 57–64.

Tinlot, M. (2010). Evaluation ex ante du bilan carbone des dynamiques de développement agricole et forestier: Application sur la filière anacarde au Burkina Faso. Mémoire de Fin d'Etudes d'ingénieur de l'Institut Supérieur d'Agriculture de LILLE, 89P.

Trade And Investment Program for a Competitive Export Economy (TIPCEE), 2009 GHANA: Assessing Economic Benefits: The Case of Banana, Mango, and Rice

Triadiati, S., Tjitrozemito, F., Guhardja, F., Sudarsoma, Quyim, I. & Leuschner, C. (2011). Litter fall production and leaf litter decomposition at natural forest and cocoa agroforestry in Central Sulawasi, Indonesia.Asian Journal of Biological Sciences, 1 (3): 221-231.

Tuffour, H. O., Bonsu, M., Khalid, A. A. & Adjei-Gyapong, T. (2014). Scaling approaches to evaluating spatial variability of saturated hydraulic conductivity and cumulative infiltration of an Acrisol. International Journal of Scientific Research in Knowledge, 2(5): 224-232.

Tuffour, H. O., Bonsu, M., Khalid, A. A., Adjei-Gyapong, T. & Atakora, W. K. (2013). Evaluation of spatial variability of soil organic carbon and pH in an uprooted oil palm field. Indian Journal of Applied Agriculture Research, 1(1): 69-86.

Tuffour, H. T. & Bonsu, B. (2014). Impact of Aggregate Size on Soil Carbon Sequestration and Aggregate Stability. International Journal of Scientific Research in Agricultural Sciences, 1(5), pp. 80-89, 2014 ISSN: 2345-6795; http://dx.doi.org/10.12983/ijsras-2014-p0080-0089.

Turner, E. R. (2006). Comparison of infiltration equations and their field validation with rainfall simulation. M.Sc. Thesis, University of Maryland, College Park.

Turner, J., Lambert, M. & Turner, S. (2017). Long term carbon and nutrient dynamics within two small radiata pine catchments. For. Ecol. Manage. 389, 1–14.

UNEP (2012). Retrieved on 10 February, 2018 from http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=485&ArticleID=5409&l=en.

United Nations Framework Convention on Climate Change (UNFCCC) (2011). Fact sheet: Climate change science - the status of climate change science today. https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf retried on 9/10/2019

USDA-NRCS, (2008). Soil quality indicators: available water capacity. Soil quality information sheet, June 2008.

Van Melle, C. & Buschmann, S. (2013). Comparative analysis of Mango Value Chain models in Benin, Burkina Faso and Ghana, In: Rebuilding West Africa's Food Potential, A. Elbehri (ed.), FAO/IFAD.

Veihmeyer, F. J. & Hendrickson, A. H. (1931). The moisture equivalent as a measure of the field capacity of soils. Soil Sci., 32: 181–194.

Verena, D., Peter, F., Karl, S. (2010). Layer specific analysis and spatial prediction of soil organic carbon using terrain attributes and erosion modelling. Soil Sci. Soc. Am. J., v. 74, p. 922-935.

Victoria, R., Banwart, S., Black, H., Ingram, J., Joosten, H., Milne, E., Noellemeyer, E. (2012). The Benefits of Soil Carbon. Managing soils for multiple economic, societal and environmental benefits. UNEP YEAR BOOK, 19 – 33.

Vieira, D. L. M., Holl, K. D., Peneireiro, F. M. (2009). Agro-successional restoration as a strategy to facilitate tropical forest recovery. Restoration ecology 17(4),451-459

Wang, B., Xue, S., Liu, G. B., Zhang, G., Li, G. & Ren, Z. (2012). Changes in soil nutrient and enzyme activities under different vegetation in the Loess Plateau area, Northwest China. Catena.92:186-195.

Wang, S. *et al*. (2018). Mapping total soil nitrogen from a site in northeastern China. Catena, 166:134-146, 2018.

Wei, X., Shao, M., Gale, W. & Li, L. (2014). Global pattern of soil carbon losses due to the conversion of forests to agricultural land. Sci. Rep. 4, 4062.

Wei, Y., Reveal, B., Reich, J., Laursen, W. J., Senger, S., Akbar, T., Iida-Jones, T., Cai, W., Jarnik, M. and Lilly, M.A. (2014). TORC1 regulators Iml1/GATOR1 and GATOR2 control meiotic entry and oocyte development in Drosophila. Proceedings of the National Academy of Sciences, 111(52): E5670-E5677.

Wen, L., Lei, P., Xiang, W., Yan, W. & Liu, S. (2014). Soil microbial biomass carbon and nitrogen in pure and mixed stands of Pinus massoniana and Cinnamomum camphora differing in stand age. For. Ecol. Manage. 328, 150–158.

West, T. O. & Marland, G. (2002). A synthesis of carbon sequestration, carbon emissions, and Net carbon flux in agriculture: comparing tillage practices in the United States. Agricultural Ecosystems and Environment, 91, 217–232.

Wiesmeier, M., Spörlein, P., Geuß, U., Hangen, E., Haug, S., Reischl, A., Schilling, B., von Lützow, M., Kögel-Knabner, I., 2012. Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. Glob. Change Biol.18, 2233–2245. https://doi.org/10.1111/j.1365-2486.2012.02699.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Luetzow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Liess, M., Garcia-Franco, N. (2019). Soil organic carbon storage as a key function of soils-a review of drivers and indicators at various scales. Geoderma 333, 149–162.

Wiesmeier, M., von Lützow, M., Spörlein, P., Geuß, U., Hangen, E., Reischl, A., Schilling, B., Kögel-Knabner, I. (2015). Land use effects on organic carbon storage in soils of Bavaria: the importance of soil types. Soil Till. Res. 146, 296–302. https://doi.org/10.1016/j.still.2014.10.003.

Winding, A, Hund-Rinke, K. & Rutgers, M. (2005). The use of microorganisms in ecological soil classification and assessment concepts. Ecotoxicology and Environmental Safety.62:230-248.

Woloszczyka, P., Fienckea, C., Elsnerb, D-C., Cordsenb, E. and Pfeiffera, E-M. (2020). Spatial and temporal patterns in soil organic carbon, microbial biomass and activity under different land-use types in a long-term soil-monitoring. Network Pedobiologia - Journal of Soil Ecology 80 (2020) 150642 https://doi.org/10.1016/ j.pedobi.2020.150642.

World Cocoa Foundation, 2014. Cocoa Market Update.

Xiao, C. (2015) Soil Organic Carbon Storage (Sequestration) Principles and Management; Potential Role for Recycled Organic Materials in Agricultural Soils of Washington State. https://fortress.wa.gov/ecy/publications/SummaryPages/1507005.html Publication no. 15-07-005 accessed on 27/05/2018

Xu, X., Thornton, P. E. & Post, W. M. (2013). A global analysis of soil microbial biomass carbon, nitrogen and phosphorus in terrestrial ecosystems, Global Ecol. Biogeogr., 22, 737–749.

Yabi, I., Yabi, B. F., Dadegnon S. (2013). Diversité des espèces végétales au sein des agro-forêts à base d'anacardier dans la commune de Savalou au Benin. International Journal of Biological and Chemical Sciences, 7, 696-706.

Yahaya, A. M., Karli, B. & Gül, M. (2015). Economic analysis of cocoa production in Ghana: the case of eastern region Article *in* Custos e Agronegocio · June 2015 ISSN 1808-2882.

Yang, Y. S., Guo, J. F., Chen, G. S., He, Z. M. & Xie, J. S. (2003). Effect of slash burning on nutrient removal and soil fertility in Chinese fir and evergreen broadleaved forests of mid-subtropical China. Pedosphere 13(1): 87-96.

Yang, Z. P., Xu, M. G., Zheng, S. X., Jun, N. I., Gao, J.S., Liao, Y. L., Jian X. (2011). Effects of long-term winter planted green manure on physical properties of reddish paddy soil under a double rice cropping system. Journal of Integrative Agriculture, 11, 655–664.

Yin, K., Zhang, L., Chen, D., Tian, Y., Zhang, F., Wen, M. (2016). Understory herb layer exerts strong controls on soil microbial communities in subtropical plantations. Sci Rep. 2016. https://doi.org/10.1038/srep27066 PMID: 27243577.

Young, K. J. (2017). Mimicking Nature: A Review of Successional Agroforestry System as an Analogue to Natural Regeneration of Secondary Forest Stands. Integrating landscape: Agroforestry for biodiversity Conservation and food sovereignty. pp 179-209.

Yu-song, D., Dong, X., Chong-fa, C. & Shu-wen, D. (2016). Effects of land uses on soil physic-chemical properties and erodibility in collapsing-gully alluvial fan of Anxi County, China Journal of Integrative Agriculture 2016, 15(8): 1863–1873. doi: 10.1016/S2095-3119(15)61223-0.

Yuste, J. C., Penuelas, J., Estiarte, M., Garcia-Mas, J., Mattana, S., Ogaya, R., Pujol, M. and Sardans, J. (2011). Drought-resistant fungi control soil organic matter decomposition and its response to temperature. Glob. Chang. Biol. 2011, 17, 1475–1486.

Zakari, A.K. (2012): Ghana National Mango Study. ITC. http://www.intracen.

Zeebe, R.E., Ridgwell, A. & Zachos, J.C. (2016). Anthropogenic carbon release rate unprecedented during the past 66 million years. Nature Geoscience. 9:325-329.

Zhang, B., Zhou, X., Zhou, L., Ju, R. (2015). A global synthesis of below-ground carbon responses to biotic disturbance: a meta-analysis. Glob. Ecol. Biogeogr. 24, 126–138.

Zhou, P., Luukkanen, O., Tokola, T. & Nieminen, J. (2008). Effect of vegetation cover on soil erosion in a mountainous watershed, Catena, 75, 319–325

Zhou, X., Lin, H. S. & White, E. A. (2008). Surface soil hydraulic properties in four soil series under different land uses and their temporal changes, Catena, 73, 180–188.

Zhu, B., Li, Z., Li, P., Liu, G., Xue, S. (2010). Soil erodibility, microbial biomass, and physical–chemical property changes during long-term natural vegetation restoration: A case study in the loess plateau. Chinese Journal of Ecology. 2010; 25 (3):531-541.

Zhu, J., Yang, K., Yan, Q. and Jin, C. (2010). Comparison of soil microbial biomass C, N and P between natural secondary forests and Larix olgensis plantations under temperate climate.19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Zimmermann, A. *et al*. (2013). Uncovering patterns of near-surface saturated hydraulic conductivity in an overland flow-controlled landscape. Geoderma, 195-196:1-11, 2013.

APPENDICES

APPENDIX A

Guide to interpretation of soil analytical data in Ghana by soil research institute (2013)

Nutrient	Rank / Grade
Phosphorus, P (mg/kg), (Blay – 1)	
<10	Low
10 -20	Moderate
>20	High
Potassium, K (mg/kg)	
<50	Low
50 – 100	Moderate
>100	High
Calcium, Ca (mg/kg) / Mg = 0.25 Ca	
<10	Low
5.0 – 10.0	Moderate
>10	High
ECEC (cmol (+) / Kg)	
<10	Low
10 – 20	Moderate
>20	High
Soil pH (Distilled Water Method)	
<5.0	Very Acidic
5.1 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.0 – 6.5	Slightly Acidic
6.5 – 7.0	Neutral
7.0 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
>8.5	Very Alkaline
Organic Mater (%)	
<1.5	Low
1.6 – 3.0	Moderate
>3.0	High
Nitrogen (%)	
<0.1	Low
0.1 – 0.2	Moderate
>0.2	High
Exchangeable Potassium (cmol (+) / Kg)	
<0.2	Low
0.2 – 0.4	Moderate
>0.4	High

Council for Scientific and Industrial Research-Soil Research Institute (CSIR-CRI), Ghana 2013

APPENDIX B

Infiltration rate of land uses and seasons

Treatment	300s	600s	1140s	1800s	2400s	3000s	3600s
Land use							
Forest	0.0841	0.0768	0.0713	0.0676	0.0646	0.0622	0.0603
Cocoa	0.0537	0.0427	0.0357	0.0314	0.0288	0.0271	0.0257
Coffee	0.0586	0.053	0.0478	0.0447	0.0422	0.0398	0.0383
Cashew	0.0331	0.0301	0.0274	0.0251	0.0238	0.0228	0.022
Mango	0.0226	0.0181	0.0147	0.0126	0.0114	0.0105	0.0098
F pr	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LSD	0.0224	0.01584	0.01377	0.01297	0.01222	0.01169	0.01131
Season							
DS2016	0.0371	0.034	0.0327	0.0307	0.0288	0.0275	0.0265
MRS2016	0.0389	0.0355	0.0328	0.0322	0.0312	0.0297	0.0289
MNRS2016	0.0317	0.0299	0.0289	0.0274	0.0264	0.0257	0.0251
DS2017	0.0553	0.0478	0.041	0.0373	0.0351	0.0333	0.0317
MRS2017	0.0585	0.0514	0.0443	0.0392	0.0362	0.034	0.0323
MNRS2017	0.0809	0.0664	0.0567	0.0507	0.0473	0.0449	0.0428
F pr	0.001	0.001	0.005	0.025	0.041	0.053	0.076
LSD	0.02454	0.01736	0.01508	0.01421	0.01339	0.0128	0.01239
Land use*Season							
F pr	0.326	0.532	0.852	0.938	0.967	0.978	0.983
LSD	0.05488	0.03881	0.03373	0.03177	0.02994	0.02862	0.0277
CV	18.1	18.7	20.3	21.4	21.8	21.6	21.8

APPENDIX C

Cumulative infiltration amount of land uses and seasons

Treatment	300s	600s	1140s	1800s	2400s	3000s	3600s
Land use							
Forest	25.2	46.1	81.3	121.6	155	186.7	216.9
Cocoa	16.1	25.6	40.7	56.5	69.2	81.4	92.6
Coffee	17.6	31.8	54.5	80.5	101.3	119.4	138
Cashew	9.9	18.1	31.3	45.2	57.1	68.5	79.1
Mango	6.8	10.9	16.7	22.7	27.3	31.6	35.1
F pr	0.001	0.01	0.001	0.001	0.001	0.001	0.001
LSD	6.72	9.51	15.7	23.34	29.34	35.06	40.71
Season							
DS2016	11.1	20.4	37.3	55.3	69.1	82.4	95.2
MRS2016	11.7	21.3	37.4	58	74.8	89.2	104.1
MNRS2016	9.5	17.9	32.9	49.3	63.4	77.1	90.2
DS2017	16.6	28.7	46.7	67.2	84.3	99.9	114.3
MRS2017	17.6	30.8	50.5	70.6	86.8	101.9	116.1
MNRS2017	24.3	39.8	64.6	91.3	113.5	134.7	154.1
F pr	0.001	0.001	0.005	0.025	0.041	0.053	0.076
LSD	7.36	10.41	17.19	25.57	32.14	38.4	44.59
Land use*Season							
F pr	0.326	0.532	0.852	0.938	0.967	0.978	0.983
LSD	16.46	23.29	38.45	57.18	71.86	85.87	99.72
CV	18.1	18.7	20.3	20.4	21.8	21.6	21.8

APPENDIX D

Textural class of the sampling sites

Spot	Sand	Clay	Silt	Texture
FT1	77.18	12.28	10.54	Sandy loam
FT2	83.18	10.28	6.54	Loamy sand
FT3	85.18	10.28	4.54	Loamy sand
FT4	79.18	12.28	8.54	Sandy loam
FT5	81.18	12.28	6.54	Sandy loam
CA1	65.18	16.28	18.54	Sandy loam
CA2	69.18	14.28	16.54	Sandy loam
CA3	73.18	14.28	12.54	Sandy loam
CA4	75.18	10.28	14.54	Sandy loam
CA5	79.18	10.28	10.54	Sandy loam
CE1	77.18	10.28	12.54	Sandy loam
CE2	83.18	10.28	6.54	Sandy loam
CE3	79.18	10.28	10.54	Sandy loam
CE4	75.18	12.28	12.54	Sandy loam
CE5	75.18	14.28	10.54	Sandy loam
CW1	79.18	10.28	10.54	Sandy loam
CW2	77.18	12.28	10.54	Sandy loam
CW3	71.18	12.28	16.54	Sandy loam
CW4	77.18	10.28	12.54	Sandy loam
CW5	77.18	10.28	12.54	Sandy loam
MO1	79.18	10.28	10.54	Sandy loam
MO2	73.18	10.28	16.54	Sandy loam
MO3	71.18	10.28	18.54	Sandy loam
MO4	65.18	10.28	24.54	Sandy loam
MO5	77.18	10.28	12.54	Sandy loam

APPENDIX E

Chemical composition of leaves from different agricultural land uses

Cocoa	**C**	**N**	**P**	**K**	**Ca**	**Mg**
1	34.12	1.34	0.10	0.62	1.77	0.26
2	35.46	1.32	0.11	0.63	1.63	0.28
3	35.94	1.29	0.13	0.63	1.73	0.26
4	34.72	1.30	0.12	0.62	1.70	0.27
5	34.94	1.29	0.12	0.63	1.71	0.27
Cashew						
1	23.96	1.28	0.12	0.46	0.33	0.26
2	24.34	1.14	0.11	0.43	0.35	0.24
3	24.68	1.42	0.12	0.43	0.32	0.23
4	24.21	1.32	0.12	0.45	0.33	0.24
5	24.44	1.38	0.11	0.44	0.34	0.25
Coffee						
1	27.7	1.77	1.75	0.24	1.83	0.21
2	27.8	1.79	1.78	0.24	1.85	0.22
3	28.4	1.76	1.72	0.23	1.82	0.21
4	27.9	1.75	1.71	0.24	1.80	0.22
5	28.2	1.78	1.76	0.24	1.87	0.22
Mango						
1	34.78	1.46	0.6	0.32	0.38	0.25
2	32.46	1.43	0.7	0.34	0.36	0.27
3	36.28	1.44	0.6	0.30	0.36	0.24
4	32.78	1.45	0.6	0.32	0.36	0.26
5	35.26	1.44	0.7	0.33	0.37	0.27