UNIVERSITY OF CAPE COAST

INFLUENCE OF LAND USE TYPES ON THE DISTRIBUTION OF SOIL ORGANIC CARBON AT DIFFERENT SOIL DEPTH IN THE UNIVERSITY OF CAPE COAST TEACHING AND RESEARCH FARM

THOMAS ABINDAW

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

SEPTEMBER, 2021

DECLARATION

Candidate's Declaration

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

Candidate's Signature: .... Date: ....

Name: Thomas Abindaw

Supervisor's Declaration

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

Supervisor's Signature: .... Date: ....

Name: Prof. Daniel Okae-Anti

ABSTRACT

Soil organic carbon (SOC) is the principal component of soil organic matter and it is broadly considered as a central indicator of soil quality due to the numerous roles it plays in physical, biological and chemical processes of soil. The study sought to evaluate the influence of different land use types on the distribution of SOC at different depth in the University of Cape Coast Teaching and Research Farm. A stratified random sampling technique was used to collect 180 soil samples at 0-15 cm, 15-30 cm and 30-45 cm depths from arable, fallow, pasture and plantation land use systems within the 24.52 ha study site. Standard laboratory methods were used for analysing the selected physico-chemical properties. Descriptive statistics and relationships among soil properties at soil depths and land use types were generated using Minitab 19. The results of the study showed that land use systems significantly affected the distribution of SOC content, including the other properties at different soil depths. Adapting land quality classification using organic carbon content as a measure was in the order of plantation (2.57 %) > arable (1.99 %) > pasture (1.55 %) > fallow (1.14 %). Plantation field is the most sustainable type of land use as it promotes the retention of organic carbon in soil in contrast to the other land use types and may therefore be adopted as a strategy to restore degraded lands. Soil organic carbon content, as well as most of the other properties, was generally concentrated within the top layers but decreased with depth. A positive correlation was established between SOC and many soil properties, so managing SOC will equally improve the availability of these nutrients towards sustainable agriculture.

KEY WORDS

Agricultural

Climate change

Depth

Land

Land use types

Soil organic carbon (SOC)

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DEDICATION

To my great family: the Abindaws'; my spouse, Susana A. Ayaaba; and children; Elvis A. Abindaw, Kelvin A. Abindaw, Emily A. Abindaw and Kendra A. Abindaw for your support, love and patience.

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LIST OF ACRONYMS

SOC	Soil Organic Carbon
CO_2	Carbon Dioxide
Db	Bulk Density
RPSMP	Recommended Proper Soil Management Practices
IPCC	Intergovernmental Panel on Climate Change
GIS	Geographic Information System
GPS	Global Positioning System
GHG	Greenhouse Gas
ISC	International Soil Carbon
ASTMD	American Standard Test Method for Density
NPK	Nitrogen, Phosphorus, Potassium
CAN	Calcium Ammonium Nitrate
ANOVA	Analysis of Variance
UCC	University of Cape Coast
NPP	Net Primary Productivity
PM	Parent Material

CHAPTER ONE

GENERAL INTRODUCTION

Background to the study

Land as a natural resource, includes every reasonably foreseeable or constant qualities of the biosphere above or beneath the surface of the earth on which human activities take place (Paper, 2016).

It encompasses the troposphere (atmosphere), soil and the geology under it, water resources, living organisms (animal population), plants, and the outcome of current and historical activities of man (Verheye, Koohafkan & Nachtergaele, 2009). Land plays multifaceted roles such as a dwelling for biodiverse species nutrient cycling in the soil environment, supply timber for human use, water storage (fresh), and control of climate and overflows (Runting *et al.*, 2017). The land resources are intertwined with the very existence of humanity as they are used to support living through food production, shelter creation, raw materials for manufacturing among others (Turner, Gardner & Sharp, 1995). Humanity's use of the earth's resources, known as “land use,” varies according to the purposes they serve; which can be food production, shelter provision, recreation, material mining and processing (Turner *et al.*, 1995).

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A large proportion of global land is use for agricultural purposes. For example, 0.37 of land worldwide is currently being used for agriculture (World Bank, 2019). However, there is a dilemma as the world grapples with climate change, shrinking agricultural land availability and population growth expected to reach 9.8± 1 billion people by 2050 and 11.2 billion by 2100 (Nations, 2018; Trendov, Varas & Zeng, 2019). The world's ability to cater for the food needs of the growing populace may be unachievable due to pressure of climate change, rise in water levels, limited land and degradation of soil and land (FAO, 2016). This leaves the world no option than adopting sustainable agricultural practices.

In Ghana, the main types of land use are agricultural and non-agricultural. According to World Bank Group (2018) about 64.97 % of the country's land is devoted to agricultural activities such as cultivation of food crops, tree crops, pasture, and rearing of animals among others while the remaining 35.3 % is made of non-agricultural uses such as forest reserves, wildlife reserves, mining, settlements, and institutional uses.

Agricultural activities through soil management practices and land use types regulate the fate of soil organic carbon (SOC) content. According to Intergovernmental Panel on Climate Change (IPCC) (2007) and Wang *et al*. (2013), about 11-12 % of greenhouse gases emitted into the atmosphere by agricultural soils is attributed to direct and indirect GHG emissions from C and N dynamics and therefore negatively impacts the environment. the Brazilian Amazon in Brazil emitted the highest CO_2 (greenhouse gas) due to changes in land use and deforestation and this attracted global attention (Galford, Soares-

Filho & Cerri, 2013). This indicates that SOC level would continually be depleted as emission of greenhouse gas increases.

Soil management practices and varied types of land uses have diverse impacts on the kind, quality and amount of carbon and carbon dioxide stored in soil or emitted from the soil respectively. Anthropogenic activities have substantially depleted SOC stocks, hence, consequential concentration of atmospheric carbon (Bellamy *et al.*,2005; Canadell *et al.*, 2007; Sanderman, Hengl & Fiske, 2017). Swift changes in SOC contents have been reported after major land use changes (Wei *et al.*, 2014). Lal (2004) projected a decline of 50 to 67 % natural soil organic carbon pool and an aggregated loss of 30–40 Mg C ha^{-1} for tilled soils. Furthermore, Guo and Gifford (2002) proclaimed that changing pasture and natural cover to cropland decreased soil organic carbon by 42 per cent and 59 per cent, respectively on average, at 0-30 cm depth.

Organic carbon is the principal component of soil organic matter, that centrally indicates soil quality (Andrews *et al.*, 2004) due to the numerous roles it performs in biological, physical and chemical processes of soil (Gregorich *et al.*, 2006). Soil organic carbon serves as source of atmospheric CO_2 or sink of carbon reckoning on the soil and its surroundings and management (Sanderman, Farquharson & Baldock, 2009), with import effects on CO_2 concentrations in the atmosphere. Soils generally store fourfold of SOC than the biosphere and over 2 times greater carbon relative to the atmosphere (Stockmann *et al.*, 2015; Le Quéré *et al.*, 2016). Eswaran *et al.* (2000) and Lal (2004 a) reported that, soil organic carbon content of about 1500 gigatons of the world's total carbon budget is more than the combination of those from the atmosphere and biosphere. Atmospheric carbon absorption capacity is directly connected to organic carbon content of the soil, the globe's ability to increase its content worldwide by 0.04% will offset all emissions and vice versa. The ability of soil to sequester organic carbon from the atmosphere and contribute about 2.344 x 10^{12} billion tonnes (one gigaton) of carbon to the organic carbon stowage globally (Lal, 2004) makes it the chief terrestrial pool (Stockmann *et al*., 2013). Agricultural activities through land use are some of the sources of greenhouse gas (GHG) emissions. In agriculture, soil organic carbon has an association with soil health and farm output (Baldock *et al*., 2009a; Sanderman, Farquharson, & Baldock, 2009) therefore, the close association between sequestration of soil carbon and food security as well as mitigation of climate change cannot be overstressed or disregarded (Lal, 2004a). Increasing SOC is helpful not just only for reducing GHG emissions and to mitigate climate change globally, but also for restoration of degraded soils (soil fertility) with inherent effects on crop productivity, food security, welfare of peasants and also the international environment (Paustian *et al*., 2016; Chabbi *et al*., 2017). Also, the global sustainable development goal 1, 2 and 15 can only be achieved through agricultural land use systems that enhance organic carbon sequestration and retention within the soil's environment.

Statement of the problem

Despite the influence of land use types on SOC, there is still insufficient information about the influence of land use systems and management (including agricultural intensity) on SOC. Estimation of local and national soil carbon level has been very difficult due to limited information on specific characteristics of soil types (Batjes, 1996), spatial disparity in soil carbon even within a single soil map unit (Cerri *et al.*, 2019) and dissimilarity impacts of determinants governing SOC cycle (Parton *et al.*, 1987).

Changes in cover and use of land have impacted SOC concentration (Lal, 2010; Smith *et al.*, 2012; Stockmann *et al.*, 2015). The alteration of innate covers to different land use systems have led to reduction of SOC, hence, diminution of soil quality and agricultural productivity. These hatched food insecurities and contributed to climate change. With increasing population and its demand for food requires sustainable management of marginal lands. Sustainable management of native vegetation is essential for agricultural sustainability and food security (FAO, 2016). Therefore, Demessie, Singh and Lal (2015) discouraged the conversion of natural forests for alternative land use types so as to reverse the accelerated degradation of native forest lands. Whereas monitoring and mediating the adverse consequences of land use and/ or cover modification on soil to continuously be used for the production of essential resources has become so crucial for researchers and policymakers (Ellis & Pontius, 2006), information on SOC disparity among land use types in Ghana is scanty.

Due to limited information, doubts still exist regarding appropriate practices that can be adopted to manage SOC under these land use types, hence, making it tough to advocate for acceptance and adoption of applicable conservation and proper land management practices (Minasny *et al.*,2017).
It is found that there is little information about the status of SOC under different land systems exists and therefore, this study sought to investigate the extent to which organic carbon behaves (is retained) under different land use types.

Main Objective

The main objective is to assess the influence of land use types on the distribution of SOC at the University of Cape Coast Teaching and Research Farm.

Specific objectives

The specific objectives are:

i. To quantify the vertical and horizontal distribution of SOC among four different land use types.

ii. To establish the relationship between SOC and selected physico-chemical properties of soil among the four land use types.

iii. To identify the most suitable land use type that retains more SOC.

Research questions

Towards realizing the aim and specific objectives, the research project seeks to answer the following questions:

i. How does organic carbon differ with depth?

ii. What is the quantity of SOC among the four land use types?

iii. What is the relationship between selected soil physico-chemical properties and SOC under the different soil depths and land use types?

iv. Which land use type retains most organic carbon in soils?

Hypothesis (H0)

1. No differences in SOC due to land use types.
2. Soil organic carbon at different soil depths is the same.
3. Soil organic carbon positively correlates with all physico-chemical properties of soil.

Significance of the study

The main novelty of the research lies on assessing SOC under different land use types. Thus, the research makes a unique contribution to knowledge of SOC assessment and the outcomes has the following significance.

i. The findings can serve as a database for further research.
ii. The outcome of this study will also provide information to farmers regarding the best practices to adopt to sustain the quantity of soil organic carbon.
iii. Government and non-governmental agencies will use the findings to formulate legislations to regulate or prevent unsustainable land use types with respective SOC depletion.

Delimitations

The research focuses on only the influence of the four land use types on the distribution of SOC at the University of Cape Coast Teaching and Research Farm. The researcher initially intended to assess SOC distribution in all agricultural land use types, soils formed from different parent material, different climate and agro-ecological zones in Ghana but the study is time bound. The study also limited its findings to the influence of different agricultural land use types on the distribution of SOC.

Limitations

Some of the predesignated sampling points were at a point altered due to intrinsic/ inherent factors such as the presence of rocks or trees at predetermined sampling points. This problem was addressed by shifting/moving those sampling points a bit farther.

Another limitation associated to this work was frequent power outages during laboratory work (analysis). This compelled the researcher to oven-dry soil samples for longer time until constant weights are obtained subject to when power was available.

Another bottleneck was inadequate laboratory equipment and faulty ones such as pH meter and lack of reagents for laboratory analysis. To address some of these challenges, the researcher had to carry shaken soil samples to other laboratories for pH determination. To overcome the lack of reagents syndrome, the researcher bought reagents for the analysis of soil properties in the laboratory.

Definition of terms

Geographic Information System (GIS) is a high-tech utensil for understanding topography and making intellectual conclusions.

Land use refers to the actions people carry out on a specific landscape to achieve an intended purpose; reflecting the people's activities and intents.

Land cover refers to the corporeal and biological features found on a particular landscape. It is the biophysical cover of the earth's surface.

Soil organic carbon: It is the carbon content confined in soil organic matter in the soil's environment. Microorganisms, biota of soil, root, plant and animal residue decay constitute the focal sources of SOC.

Agricultural land refers to land that is devoted to agricultural activities (purposes) comprising arable land, land under permanent crops, and pastures.

Soil depth: refers to how deep the soils are sampled, ie the height of the sampling pit. It is the vertical distance between the soil surface and the points within which soil samples were collected (pit's height).

Global Positioning System (GPS) is a satellite navigation system that locates (determine) the exact location of an object on the ground. GPS is an application used in picking exact points on the earth's surface by showing the coordinates for the latitude (x) and longitudes (y).

Organisation of the study

The write up comprised five chapters. Chapter one was designated to the introduction which briefly described background to the study, statement of the problem, purpose of the study, specific objectives, research questions and hypothesis, delimitations, limitations, definition of terms and organisation of the study.

Chapter 2 dealt with literature review on the stated objectives. The review explained key concepts in the work such as; brief overview of land uses and their changes, factors that influence land uses, effects of land use type on SOC. Also, the chapter includes theoretical concepts on soil, and SOC, factors affecting soil organic carbon, relationship between SOC and soil depths and the relation between organic carbon and selected properties of soil.

Chapter three mainly deals with materials and methods that include brief description of the study area, field characteristics, field work, research design, data collection, organisation and analysis. Included in the fourth chapter were results of analysis and chapter five deals with discussions of the results. and summary of findings.

Chapter six comprises summary, conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

Land use

Land use fundamentally describes the activity(ies) being carried out on the physical land and its resources by humans for various purposes in a given location (Joint, F. A. O. & World Health Organization, 1999). It can also be described as the set of input(s) as well as action(s) undertaken by folks on a particular piece of land (Shukla *et al*., 2019). Land and its resources can be utilised for agricultural, commercial, residential, recreational, industrial among others. Such uses encompass the management and conversion of natural or bare lands into man-made environments such as built-up areas and semi-natural habitation (arable sites, grazing land and managed woodlands). Land cover on the other hand consist of flora, water resources, surface land, road and rail network, edifices, as well as constructed essentials supportive individual's arrangements. Land (soil) cover is the biophysical characteristic of land while land use connotes the functional aspect of land; or Land use basically is the source or origin of cover changes and land cover fundamentally defines the impacts/consequences brought after change in use of parcels.

Land use change

Information on land use is a very imperative pointer for SOC storage at both local and subcontinental level (Wiesmeier *et al*., 2019); changes in land use account for inconsistency in SOC (Guo & Gifford, 2002; Viscarra Rossel, Webster, Bui, & Baldock, 2014). Studying the inverse correlations between land use change and distribution of SOC are vital for carbon management for ensuring sustainable use of land. Changing the use of land may influence the extent of carbon detained in plants cover and soil and therefore either promotes carbon retention by sequestering atmospheric carbon dioxide or emitting carbon dioxide (a greenhouse gas) into the atmosphere. Right from the period people started cultivating on pieces of land for close to over 12,000 years now, soil organic carbon stocks equally began fluctuating in these landscapes. Since 1850, degraded lands (soils) have lost 44-537 petagram of SOC through human activities (land conversion to agriculture) across the globe (Lal, 2001). Between 0.2-0.75 (30-40 Mg C ha^{-1}) of soil organic carbon pool in agricultural lands (soils) have been lost worldwide (Lal, 2015). Land use change results in dissimilarities in SOC stocks, for instance, an average increase of 53 per cent and 19 per cent of SOC stocks were recorded when cropland was converted to secondary woodland and cropland replaced pasture respectively (Govers *et al.*, 2013)**.**

Inadequate information exists in relation to the effects of managing grassland on SOC storage due to inadequate information and substantial spatial variation of organic carbon content in soils under grassland (Soussana *et al*., 2004). Despite less data on grassland management effects, Conant, Paustian and Elliott (2001) and Soussana *et al.* (2004) found that grassland management practices substantially influenced SOC storage in temperate grasslands. Intensive grazing depletes SOC in grasslands dominated with C3 however, improves C4 and C4-C3 mixed grassland (McSherry & Ritchie, 2013).

The unprecedented conversion of forest or grasslands for crop cultivation in several parts of the world has significantly and rapidly resulted in SOC stock reduction as was first noted by Houghton *et al*. (1983). An exorbitant reduction in SOC pool amounting to sixty per cent in temperate soils and seventy-five per cent or more in tropical soils were observed when native lands were converted to agricultural bionetworks. Martin *et al*. (2011) and Meersmans *et al*. (2008) noticed that SOC storage decreased in the order; grassland > forest > cropland. Conversion of grassland or woodland (forest) for crop production causes a depletion of SOC between 0.3-0.80 (Guo & Gifford, 2002; Wei, Shao, Gale, & Li, 2014). Similarly, Guo and Gifford (2002) reported that when woodland (forest) is replaced with arable land, SOC stocks decline by 0.4 in soils. They noted an average drop in soil organic carbon stock of forty-two per cent and fifty-nine per cent corresponding to the conversion of woodland to cropland and from pastures to cropping fields. The diminution of SOC stocks trend is aggravated where soils are severely degraded as well as where carbon input is less than output. Carbon lost through emission into the atmosphere from certain soils ranges between 20-80 tons of carbon per hectare.

A significant diminution of SOC pool gives rise to decline in quality of soil, diminishes biomass productivity and unfavourably affects the quality of water, and further declination will exacerbate anticipated global warming. Decline in soil quality due to low organic-input in arable land on average decreased yield by 30 % in agricultural sector (Seufert *et al*., 2012).

A consistent increase in atmospheric carbon dioxide between 800 BP -1000 BP was approximately 8% (260 ppm to 280 ppm) due to the early clearance of forest; resulted in an emission of 300 Pg carbon into the atmosphere from soil (Ruddiman, 2003).

Finally, investigations on the impact of land cover changes on SOC revealed an estimated increase in carbon loss into the atmosphere between 1850-

2000 or 1850-1990 to be approximately 74 % (108-188 Pg C) (Pongratz *et al*., 2009): these losses though greater than were observed by Eglin *et al*. (2010). In general, detail work is imperative for elucidating the range of influential factors controlling SOC stock dynamics (Gray, Bishop & Wilson, 2016). Marland, Obersteiner and Schlamadinger (2007) also advocated for long-term studies on soil organic carbon distribution across various types of land uses.

Generators of land use changes

The core causes of change in land uses are direct (proximate) and indirect (underlying) factors. These factors comprise pressure from population growth and, mining of soil, farm size fragmentation to land tenure systems; as well as the quest for meeting food demand of the world and excessive land resources exploitation; resulting in degradation of biodiversity and forest cover depletion globally (Kissinger, Herold & De Sy, 2012).

Direct drivers of land use change

Proximate causes of forest clearance (conversion) include activities of man which directly impact the native cover and these include urban growth, extensification of agriculture, mining and construction of infrastructures (FAO, 2016). (Kissinger *et al*., (2012) attributed agricultural extensification as the immediate cause for nearly eighty per cent of forest depletion internationally. Even though, increasing agrarian activities may probably bring some proceeds and eliminate food insecurity worldwide, extensive and export-based marketable agriculture may add insignificant increment in the food basket at the home-grown or nation-wide levels.

They also discovered that commercialized agriculture is ravaging ubiquitous initiator of native cover removal, amounting to 40 % of total native forest resources. Nonetheless, according to DeFries, Rudel, Uriarte and Hansen (2010) and Fisher (2010), just a third of forest cleared in Africa is attributable to commercialized agriculture but likely to increase (Hosonuma *et al.*, 2012) as a result of growth in global markets (Megevand, 2013). Indigenous subsistence agriculture on the other hand, books a projected 33 % of deforestation; meanwhile, WRB (2014) declared that peasant farming systems are the key drivers of land clearance in Africa, especially among sub-Saharan regions where majority of these poverty engulfed farmers rely on only traditional methods of cultivation for survival. Other direct drivers of land use change such as urban expansion, infrastructure and mining cumulatively contribute 27 % to forest depletion but in certain instances, land use modification resulted in untenable lumbering leading to complete vegetation cover depletion (Hosonuma *et al.*, 2012).

Indirect drivers of land use change

As the world's population doubled from the 1970s to 7.7 billion in recent times with an increase in human population close to thirty-seven per cent from 1990 till now correspondingly increased demand for food to a tune of forty per cent FAO (2016) resulting to close to seventeen per cent increment in per capita food consumption between 1970s and 2012 while changes in taste led to increased consumption of diets from vegetable oils and products to livestock (Alexandratos & Bruinsma, 2012). Rapid population growth coupled with changes in taste concurrently increased demand for produces from agricultural sources in cities across the globe (DeFries *et al.*, 2010). This results in astronomical conversion of potent lands for agricultural uses in an untenable manner.

Favourable agricultural policies (Planting for Food and Jobs in Ghana), preferential access to land; better transportation, better market environments and improved technologies that enhance productivity attract investment in agricultural sector, hence, increasing demand for more reserved lands for agricultural activities that results in increased forest clearance. Low income and literacy levels couple with unsustainable practices among farmers in agricultural systems also make native lands vulnerable particularly in areas where people seek economic opportunities on forestlands. While tenure insecurity affects the future economic potentials derived from forest resources in relation to economic returns generated currently from agriculture, hence, discouraging forestlands preservation for current modifications (Barbier & Burgess, 2001), security of tenure is the surest way for curbing unnecessary clearance of native vegetation (Robinson, Holland & Naughton-Treves, 2013).

Classification of land use types

Land degradation is one of the foremost adverse issues presently impeding agricultural productivity in Ghana including other developing economies within the tropics. And one of the vital factors influencing land degradation is land use systems (Senjobi & Ogunkunle, 2010).

The major land use types in Ghana could be categorized as agricultural and non-agricultural. Hence, this work is limited to the dominant land use types such as fallow (abandoned), plantation, arable and pasture lands in the School of Agriculture Teaching and Research Farm.

Fallow land

Fallow land is defined as a piece of previously cultivated land left uninterrupted for one or more years to enable the soil regain its fertility for future use. Fallow is usually practised to ensure that the land recuperate and store organic carbon while retaining moisture among other properties. Fallow protects biodiversity by ensuring the presence of predators for pest control (Traba, & Morales, 2019). Fallow includes land left to establish shrubs, herbaceous and sparse vegetation in nature, and other restricted precincts (Gong, 2009). According to Latham *et al.* (2014) about 42.9 % of total land area globally is predominantly vegetative (forestland (27.7 %) and barren land (semi-arid areas) (15.2 %)) in nature. Fallow land consists of different semi-natural pastures and grasslands that may eventually be cultivated in future (Peco *et al.*, 1999). Approximately 1.8 billion hectares of vegetative lands have been lost globally for the past 50 centuries and may become fallow. Archaeological and past studies attributed global increase in fallow to increase population growth with a corresponding increase in demand for land for agriculture and untenable uses (consumption) of forest resources (FAO, 2016).

An established fallow provides food for diverse species, timber, habitat for wild species, medicinal materials and raw materials; while regulation of climate change and reduction in floods and erosion cannot be underestimated.Managing fallows adequately is one of the most important ways of restoring soil fertility, sequestering atmospheric CO_2, restoration of wildlife and increasing abundance of food resources such as weeds, seeds, and invertebrates, as well as vegetation cover for foraging in the agricultural landscapes (Morales *et al*., 2008) Fallow land serves as the only alternative habitat where limiting resources such as food or adequate nesting sites are found in intensive and extensive agricultural landscape (Berthet, Bretagnolle, & Segrestin, 2012).

Arable land

Agriculture land is any parcel devoted for agricultural purposes, hence, its uses are generally defined by agronomic schemes and the sort of crops grown; that can differ from biological schemes (perennial or annual crops using little pesticides or fertilizers) to intensively managed monocultures (Gong, 2009). Arable land covers close to 13 % of the world's land area (Latham, Cumani, Rosati, & Bloise, 2014). Arable lands are lands used for cultivating temporary crops especially foodstuffs having a growing cycle less or more than a year such as groundnut, soy beans, okro, maize, strawberries, pineapples among others (Gong, 2009). Less than two per cent of SOC are concentrated in most agricultural soils especially in temperate zone. Deforestation and different land use adjustments to amplify the surface region for production of crops in addition culminates to global warming. Converting native ecosystems to annual cropping systems mostly degenerates to depletion of SOC (Lal, 2004). Luo *et al.* (2011) observed that due to continuous cultivation for over four decades, close to fifty-one per cent of organic carbon within 0-10 cm of soils in Australian agroecosystems got depleted. In addition, farmland generally represents management practices that (e. g. intensive farming, fertilizer application and other chemicals), increase GHG emissions.

Pasture land

Pasture or meadow lands are lands used for growing of crops such as herbaceous forage for feeding animals or for recreation. Pasture land may be temporary or permanent with the latter being pastures permanently used for five or more years (Gong, 2009). Globally, permanent grasslands cover approximately 32 % of the total land area and 70 % of lands used for agricultural purposes (FAO, 2014, 2015). Pasture lands can be natural (rangelands) or artificial (man-made pastures). High GHGs emitted from above-average and grassland cover underscore the potential of rangelands and grasslands of mitigating global warming. Some studies also found that SOC level will increase within the upper soil layers once native vegetative covers are replaced with pastures but declines at deeper depths (Eclesia, Jobbágy, Jackson, Biganzoli & Pineiro, 2012) while another workers found the reverse (alternative) (Don, Schumacher & Freibauer, 2011) because of the influence of environmental conditions, together with precipitation, temperature, and soil attributes (Laganie`re, Angers, & Pare´, 2010), hence, there is no agreement.

Plantation land

Plantation consists of a piece of land with economic crops made of rubber, coffee, tea, oil palm, coconut among alternative tree crops is fully grown along, particularly, in tropical countries (Nasution, & Kartodiharjo, 2021). Plantation field within the studied site mainly consists of oil palm and coconut trees. Tree plantations substituted with savannahs or fallows generally decrease the content of soil nutrients due to increased uptake (Nosetto, Jobbágy, & Paruelo, 2005; Farley *et al.*, 2008; Guo *et al.*, 2008). Substantial amounts of C can be accumulated in the biomass of tree crop plantation, but in some tropical ecosystems, depletes very fast (Guo & Gifford, 2002).

Land use changes relating reciprocal surrogates between tree-dominated cover and grass alters the quality, quantity and vertical distribution of SOC (Eclesia *et al.*, 2012). The content and distribution of SOC over a landscape varies in keeping with the character of vegetative cover that dominates the system (Jobbágy & Jackson, 2000). Literature discovered that SOC changes with soil depth were temporary of original natural plants but powerfully keen about the present land cover, its age, and precipitation (Eclesia *et al.*, 2012). Guo and Gifford (2002) ascertained that older plantation had higher SOC contents compared to younger plantations.

Conversely, other scholars reported no disparity in SOC of matured and newly grown plantations (Fialho & Zinn, 2014). Eclesia *et al*. (2012) found no clear influence of land use conversions on SOC fluctuations in terms vertical and horizontal distribution, quantity and, quality. There is less agreement regarding information superhighway effects on SOC when replacement with perennial (tree) crops plantation.

Concept of Soil

Soil fundamentally consists of different sizes, shape, collection of mineral particles and organic carbon at various stages of disintegration (Nenadović *et al.*, 2010). According to Herrick (2000) soil is fundamentally where every activity of humans takes place including production and profit while Arshad and Martin (2002) view the combination of soil and water as the most vital natural resource of our physical environment. Monetary quantification of earnings on investment in soil management is difficult whereas the consequential effects of today's management practices may be noticeable for only after several decades.

The numerous functions soil serves in current times are highly acknowledged as critical facet in the management of land globally (Wiesmeier *et al.*, 2019). Soil is a natural sink or source for carbon (Batjes, 2001); and its capability to impound carbon is well underscored, containing almost 2,344 gigatons of organic carbon stored worldwide (Lal, 2004a), placing soil the gargantuan terrestrial reservoir for storing organic carbon (Stockmann *et al*., 2013). Soils that contain approximately 0.05 of organic carbon, 0.45 non-living substance and the remaining 0.50 equally filled with moisture and gas are said to be fertile. Soil quality is generally viewed as an ideal pointer of sustainable land management (SLM) as acknowledged by few land administrators (Herrick, 2000). By extension, soil is seen to be quality if it is capable of promoting the health of animal and plant, sustain productivity of animals and plants as well as ensure maintenance or enhancement of environmental quality (air and water). Basically, food security, environmental quality, and economic viability are consolidative pointers anchored to soil quality

The notion of functions of soil was established in a manner to cover every single part of soil-based eco-friendly, economic and social services (Baveye, Baveye, & Gowdy, 2016). According to Wiesmeier *et al*. (2019), principal innate role of soil including cultural and technical dimensions are; retention of water and nutrients, production of biomass, place of abode for biotic organisms, nutrients recycling and reservoir for storing carbon. Carbon plays key functions in soil, as it is not only a decision rule for regulating climate, but also equally robustly influences other important roles too. Soil organic carbon as master pointer of soil quality (Andrews *et al*., 2004) plays vital roles in soil's physico-chemical and biological processes (Gregorich *et al*., 2006). More precise and numerical information on peculiar soil functions have been created through the fusion of soil functions in eco-friendly policy making in modern times (Lehmann & Stahr, 2010; Schulte *et al*., 2015; Baveye *et al*., 2016). However, straight forward examination of the key roles of soil will necessitate holistic cost analysis including labour, though very cumbersome in large scales spatial analysis (Wiesmeier *et al.*, 2019).

Relationship between selected properties and soil organic carbon

Efficiency and sustainability of soil hinge on the dynamic equilibrium amid its properties (Somasundaram *et al*., 2013). Maintaining the quality of soil properties is increasingly becoming central and the key indicator for sustainable agriculture under increasing demands for biodiversity preservation, climate change mitigation and environmental quality (Blanco-Canqui *et al*., 2013). Some properties of soil land use systems unendingly influence under the current study include texture, moisture content, bulk density, exchangeable cations, exchangeable acidity, available phosphorus, total nitrogen, pH and organic carbon.

Soil Physical properties

Physical properties of soil regulate how water and air or substances in solution behave in soil and determine circumstances controlling root growth, germination, and erosion mechanisms. These properties form the basis of many biological and chemical activities that control the position of the landscape, climate, and uses of land. Therefore, modifications in climate could activate chains of reactions that result in disruption of soil structure complex that may hugely lower crop productivity. The physical indicators of climate change influence on soil properties include rate of water infiltration, stability of aggregate, bulk density, surface cover of soil and rooting depth (Jat *et al.*, 2018).

Texture

Soil texture largely describes the grittiness or smoothness of soil (fraction of clay, silt and sand). Soil texture is referred to as clay, silt or sand if its particle sizes are less than 0.002, 0.002-0.05 and .05-2.0 mm respectively according to the texture triangle (Jat *et al*., 2018). The role soil texture plays on numerous properties of soil is significant. For example, water holding capacity and carbon retention within the top soil largely depends on soil texture; with clay being the best to harness these properties. According to some studies, fine fractions (clay and silt) have the ability to retain more soil organic carbon than sandy fractions (Ruiz-Sinoga, Pariente, Diaz, Martinez & Murillo, 2012). It is evident that the nature and amount of clay content account for the distribution of SOC accumulated (McLauchlan, 2006) across fields. Soil texture type influences organic carbon level in soils with loamy soil recording the highest average (15.42 g kg^{-1}) and sandy soil recording the lowest (7.55 g kg^{-1}). Soil organic carbon content was high in dense-textured soils whereas light-textured soils contained low content of SOC which followed similar pattern with McGrath and Zhang (2003) report. There is a direct relationship between SOC and the amount of clay content. Clay content slows the rate of mineralization of more recalcitrant SOC pools, hence, faster accumulation of SOC in clay soils (McLauchlan, 2006). Clay particles are capable of protecting SOC in different mechanisms. For example, humified SOC may stabilized and be adsorbed onto negatively charged clay minerals with high surface area. The presence of clay particles facilitates the hierarchical aggregate formation process (Six, Paustian, Elliott & Combrink, 2000). The concentration of clay may alter moisture level in soil which in turn affects both SOC decomposition and C inputs to soils via plant productivity. The regional pattern of accumulated SOC could be determined by the interactions between changes in land systems and soil texture (Berthrong *et al*., 2012).

Soil structure

It shows how soil particles are arranged; this controls organic carbon (C) accumulation, circulation of soil air, infiltration capacity of nutrients in solution and moisture, crops and root development, and activities of microbes within the soil. It also regulates the erosion resistance level and manage variations in the soil (Moebius *et al*., 2007). Soils with large amounts of clay, especially smectite mineralogy, have high tendency shrinkage during drought, resulting to large development of cracks and fissures. When agricultural clay soils dry and shrink, they become more difficult to manage (Jat *et al.*, 2018). Soil management practices and content of carbon determine the quality of soil structure. For instance, depletion of carbon degrades the aggregate stability of soil due to climatic influences. Decline in soil aggregation due to low organic carbon paves way for surface erosion due to compaction and low water infiltration (Jat *et al*., 2018).

Moisture content

Soil moisture is content of water in soil for crop use, and dissolve nutrients in soil. The rate of soil water infiltration is becoming important in soil moisture content modelling (Dalal & Moloney, 2000) as it plays enormous role in soil and plant growth. Moisture is critical during decomposition of organic carbon, hence, affects the fertility of soils. Soil moisture does not control only net primary production and SOC input but in addition, activities of microbes and soil organic carbon output. Unstable moisture level disrupts activities of microbes due to reduced oxygen, which favours the build-up of SOC. Soil moisture thus was acknowledged for its significant role played towards the distribution of SOC spatially in numerous local works (Mayes *et al.*, 2014). Soil moisture can significantly be altered by soil management, use, and time. Changes in climate substantially and rapidly influence the availability and distribution of soil water exclusively during periods of fluctuating and high-intensity rainfall or drought events.

Bulk density

Intensive agricultural practices increase bulk density of croplands (Oguike & Mbagw, 2009). In soil quality assessment, quantitative estimates of bulk density and SOC need to be considered (Wilson, Growns & Lemon, 2008). Bulk density connotes the quantity of dry soil measured per unit bulk volume. It is most typically utilized in agriculture once investigating compaction layers that occur between 0.1– 0.4 m as a result of machinery and stock impacts and to see numerous nutrient levels and different soil quality indicators on an area basis. Bulk density of mineral soils ordinarily ranges between 1.1-1.5 g cm^{-3} in upper horizon. Increase in bulk density of farmland reflects the extent of soil degradation as established by several researchers (Guilser, 2006). It tends to increase with depth, in sands and compacted pan horizons, but low in carbon-rich soils. Soil bulk density epitomises a measure of soil compaction and health. High bulk densities correspond to low penetrability. Lower soil bulk density implies less compaction of the soil, resulting in high retention of water in the soil for plant use and less runoff whereas high bulk density indicates high compaction of soil, leading to low retention of water and increased runoff within the field.

Conversion of forest (native lands) to other land uses (farmland and grazing land) increase soil bulk densities which is attributed to increase in soil compaction. It is a regularly assessed property of soil in farming schemes that portray the level of soil compaction, infiltration and aeration, (Reynolds, Drury, Tan, Fox & Yang, 2009). Spatial variation of density can be attributed to texture of the soil, organic carbon content, and soil management practices (Wolf & Snyder, 2003). Gülser *et al.* (2016) reported that, bulk density of soil has a momentous inverse association with organic carbon and Nanganoa *et al*. (2019) clay content. Bulk density estimation is critically needed for the calculation of SOC stock estimates. Iqbal *et al*. (2005) noted that when the existence of macro porosity and plant root passages increase, the bulk density of soils decrease and the values of hydraulic conductivity decline in the outer horizons. As bulk density generally correlates inversely with SOC (Weil & Magdoff, 2004), reduction in organic carbon from decomposition due to increased temperatures may account for increased bulk density; hence, making soil more susceptible to compaction through poor land management and climate change stresses (Birka, Dexter & Szemok, 2009).

Soil Biological properties

The biological properties are associated with biological activities on organic carbon, which includes microbial biomass carbon and soil respiration. Some of the indicators of biological properties include diversity, food chains, abundance, stability of communities, and organisms associated to mesofauna such as earthworms, nematodes and arthropods which are used as soil restoration. Enzyme activities potentially mineralized nitrogen or CO_2.

Soil Chemical properties

Biotic property of soil is a complex adaptive system that combine key soil processes. It is made up of organic carbon including its constituents as well as microbial biomass of soil which can be affected by climate change (Jat *et al*., 2018). Kibblewhite, Ritz, and Swift (2008) reported that soil biota is adaptive to variation due to differences in environment. Soil organic carbon is primarily obtained when oxidized atmospheric carbon is transformed by plants to biomass during photosynthesis, and eventually transferred into soils through decomposed litter fall or plant material (Jat *et al*., 2018).

Soil organic carbon is complex and has diverse composition in soils, thus often grouped into compartments or pools with regards to their rates of decomposition as; rapid (microbial, labile, active,), slow (unprotected and intermediate), or resistant (non) (inert, intractable, or protected). There are numerous functions of soil organic carbon including: its roles as a charging property of soils, source and sink of C and nitrogen and regulation of phosphorous and sulphur cycling, provide microbial and faunal habitats by producing complexes with multivalent ions as well as organic compounds together with substrates. It also affects water retention, trafficability, aggregate stability and hydraulic characteristics of soils (Weil & Magdoff, 2004). Kuzyakov and Gavrichkova (2010) found that microorganisms largely determine availability, accessibility and losses of SOC rather than climatic factors such as temperature.

Nonetheless, reduction in soil organic carbon leads to declined fertility, biodiversity and loss of soil structure resulting in high risk of erosion, lower water holding capacity, and increase in bulk density resulting in hardening of soil (Weil & Magdoff, 2004). According to Jat *et al*. (2018) erratic moisture, and temperature as well as land use types and management practices strongly control SOC.

pH

pH measures the acidity and alkalinity of soil solution using a scale ranging 0-14. The amount of hydrogen ions in solution determines the pH of soil (Scientist, Jones & Olson-rutz, 2017). pH is used to assess nutrients' deficiency potentiality in soils, amendment needs of pH, crop suitability, and for the determination of proper methods to use in testing nutrients of soils, for example, available phosphorus (Scientist *et al*., 2017). Soil pH is dependent on plants, weathering time, climate, and parental material; it affects a variety of chemical and biological functions of soil: acidification, salinization, pedalling of available nutrients, crop performance, and biotic activity (Dalal & Moloney, 2000). Key factors that dictate the status of pH in soils include temperature, precipitation, land and soil management practices, sources of nitrogen fertilizers, decomposition of organic carbon, mineral and parent rocks disintegration. High precipitation results in leaching of base-forming cations and lowers pH of soil (Scientist *et al*., 2017). Variation in pH throughout landscapes (fields) impacts the fertility of soils due to its results on many soil properties, heavy metals and microbial activities. pH degree in soils is very quintessential at some stage in the conversion of nitrogen (N), nitrification and fixation of N. At low pH (< 6.5) or excessive pH (> 7.5), many macro and micronutrients emerge as unavailable (or are reduced) and microbial activities are substantially reduced. Low pH value (< 5.5) makes Al, Mn, and Fe greater soluble. At low pH, Al and Fe bind P and creates toxicity of heavy steel and vice versa. Acidic soils (pH < 5.5) cover 0.3 of total land globally and majority (0.6) of tropical soils and specifically, widespread in humid zones (Fujii, 2014). Acidic soils can be remedied via liming to obtain pH beneficial for most flora

On the other hand, many plants do nicely at pH values past mid-acid (5.5). At excessive pH values, calcium binds phosphorus, making phosphorus inaccessible to flora and rendering the soil infertile. High pH creates toxicity of molybdenum due to immoderate availability. Nutrients come to be reachable at the greatest pH value of 6.5 (Havlin, 2014). In general, SOC and total nitrogen negatively correlate with soil pH values (Samani, Pordel, & Hosseini, 2018).

Exchangeable cations

Exchangeable cation determines the magnitude of cations control within soil colloids. Variation in soil properties (clay content, organic carbon level and pH) affects EC, therefore the fertility of the soil. The quantity of exchangeable cations, depends on pH scale, clay content and organic matter content of soil. Increase in exchangeable cations, in soil will increase the supply of nutrients for plant use. High cation exchange capacity increases the soil's strength in holding each applied and native nutrient for plant's use.

Again, the existence of calcium and magnesium in soils enhance organic carbon stabilization (Kaiser *et al*., 2012). Exchangeable calcium can be used to predict accumulation of SOC in different land use types (Kaiser & Kalbitz, 2012). O'Brien, Jastrow, Grimley and Gonzalez-Meler (2015) observed that SOC strongly correlated with Ca^{2+}. This explains why Ca^{2+} can strongly be used to predict SOC content compared to texture in lands that have been restored. Lack of vegetative cover accelerates depletion of potassium level in many agricultural landscapes. Potassium as a parent material dependent (Samani, Pordel, & Hosseini, 2018) leaches easily (Weil & Brady, 2016) and does not exist in organic carbon (Salardini, 2011). Naturally, SOC contains little amount of K but easily losses more of the derived-K from tissues of dead plants via rains

(Weil & Brady, 2016). Potassium is added to soil solution during disintegration of mineral (Weil & Brady 2016). The crown of trees affects the level of K returned to soil (Hajizaki, 2009) through slow decomposition rate and chemical destruction of K contained minerals (Mishra, Sharma & Khan, 2003), increased ion exchange capacity and release of absorbed K in plant residue into the soil (Karamain & Hosseini, 2016). Generally, reduction of K in agricultural land use types can be attributed to extensive water erosion, lack of permanent vegetation, and low cation exchange capacity (Salardini, 2011).

Available phosphorus

Phosphorus performs an indispensable function in plant growth including root development and consequently its deficit can have tremendous terrible consequences on yield (Foth & Ellis, 2018). Phosphorus deficiency in soil is caused by crop harvest (Meng, Fu, Tang & Ren, 2008) and low pH which makes bound-phosphorus inaccessible to plants. High clay content material additionally restricts the availability of phosphorous in soils (Singh, Goyne & Kabrick, 2015). According to Willy, Muyanga, Mbuvi and Jayne (2019), OC positively correlated with P, hence, a reduction in carbon correspondently decreases the quantity of accessible phosphorus (P) in the soil.

Total nitrogen

There is positive relationship between N and OC contents amid numerous land use systems (ie cropland, grazing, native cover). Inadequate organic carbon input contributed to low nitrogen level among land use types (Yu *et al*., 2014). Low organic carbon clearly ends up in a corresponding decrease in quantity of nitrogen (N) beneath cultivatable lands previously covered with vegetation (Samani *et al*., 2018). Total N levels in agricultural lands is regulated by the quantity of humus and plant litter and consistency of soil caused by plowing; that finally disrupts the N cycle. Total nitrogen level is largely defined by the amount of soil organic carbon (Shukla, Lal, Ebinger & Meyer, 2006).

Soil organic carbon

The usefulness of soil organic carbon (SOC) in the environment goes beyond viewing it from soil quality perspective, as it includes its potential impact on variations in the global SOC pool. Internationally, the need for effective management of carbon in soil will continue to be the priority of humans because of the exponential changes in global climate in the twenty first century (STAP, 2012); and changes in global climate is predominantly affected by equilibrium between emission and retention of organic carbon across the globe (Govers, Merckx, Van Oost & Van Wesemael, 2013). Fluctuations (losses and gains) related to SOC mostly come, because it is factual that soil organic matter (SOM) is not solely made up of C, but in addition, contains substantial quantities of organic nitrogen and organic phosphorus that promote SOC sequestration when available (Kirkby *et al*., 2011). Furthermore, SOC may potentially counterbalance emissions of 0.05-0.15 globally (Okolo, Gebresamuel, Retta, Zenebe, & Haile, 2019).

Soil organic carbon is an invaluable natural resource (Lal, 2004); therefore, conserving it may correspondingly improve the quality of soil for a sustainable agricultural production. An increase in organic carbon levels in soils indirectly contributes to high crop yield among farmers. Soils that sustain OC perform better in providing countless functions necessary for better-quality crop production. Notwithstanding water retention, resistance to erosion, buffers nutrients and pH, structural stability of soil, and higher agronomic efficiency due to inputs from fertilizers (Vanlauwe *et al*., 2011); high SOC stock is imperative for increasing or maintaining output through enhancements in nutrient holding capacity and biotic activity (Lal, 2004). Although, improved soil C seizure sustains biomass/ agronomic productivity and currently reduces the CO_2 emission rates from soils (Okolo *et al*., 2019), increasing SOC concentration from low (0.1- 0.2 %) to critical level (1.1 %) is a key contest for bionetworks of the tropical zones.

Although there are different philosophies regarding the factors accounting for SOC variability, many studies have shown that land use and management essentially affect total SOC stocks. Hence, critical examination by scientists in providing a clearer consideration on sequestration of SOC and dynamic forces in the midst of changing climate (Okolo *et al*., 2019). In addition, to meet the world's food need by 2050 with minimal negative impacts on the environment will mean demand for a shift from intensive agriculture in well-endowed nations and wanton clearing of land among developing economies for moderately intensified agriculture in the low productivity countries (Tilman, Balzer, Hill & Befort, 2011). So, radical decline in organic carbon pool in soils under sub-Saharan Africa among others should be inverted so as to eliminate hunger and food insecurity, leverage people from perpetual poverty, hunger, malnutrition, and substandard living (Lal, 2004).

Carbon pool

Soil carbon (SC) pool is a heterogeneous blend of various fractions of soil organic matter (SOM) at all stages of decay. Therefore, the constituents of soil organic carbon (SOC) constitute carbon pools (Trumbore, 2000). The impact of environmental dynamics reminiscent of the number of elements such as nitrogen amount, soil texture, pH, the character of vegetation, the character of the soil and land use systems on SOC is unsure (Wei, Xiao, Zhang, Li & Li, 2006). Agricultural activities have significantly reduced soil organic carbon pool to a tune of sixty per cent in previously undisturbed soils in temperate regions and to at least seventy-five per cent in soils in tropical regions (Lal, 2004). Despite the indecisions in projecting the average quantity of carbon (C) in soil taxonomic biome or order (at 65 % coefficients of variation), current projections for soil C pool worldwide congregate (Jobbágy & Jackson, 2000; Hiederer & Köchyl, 2011), represent a dynamic equilibrium of expansions and reductions (Lal, 2004). International soil carbon (ISC) pool amounted to 2,500 gigatons (Gt) consists of thirty-eight per cent of soil inorganic carbon (SIC) whiles the remaining sixty-two per cent forms SOC. Organic carbon pool in the universe is in the order: soil (0.65) > atmospheric (0.20) > biotic (0.15) (Lal, 2004).

Nevertheless, it has also been proposed that carbon confined in soils ranges between 1400-1600 Pg within 0-1 meter (upper meter) depth of soil but 500-1000 Pg in the next depth (1-2 m) worldwide (Govers *et al.*, 2013). Carbon content of soils has direct influence on agricultural productivity in that an increase in carbon pool up to a tonne in degraded soils will probably boost output of cowpea, maize and wheat, by 0.5-1, 10-20 and 20-40 kg ha^{-1} accordingly; as well as preventing food insecurity while carbon sequestered potentially replaces 5-15 % of fossil-fuel-emitted carbon worldwide every year (Lal, 2004). On the other hand, even little changes in carbon pool within the soil has devastating effects on greenhouse gas balance and agricultural productivity.

Carbon exchange between land and atmospheric basins through photosynthesis and respiration is 120 Pg C annually in both directions (Houghton, 2003). Internationally, carbon sink capacity of cultivated and degraded soils is 0.5-0.66 as against momentous carbon losses that ranged between 42-78 gigatons (Cotching *et al.*, 2013). The SOC sequestration rate for the adoption of the recommended technologies depends on the structure and texture of the soil, climate, farming system, and soil management practices. Carbon contents in soils largely depends on how the soil is managed as well as the kind of use the land is subjected to; for instance, it is known that cropping sites have reduced soil carbon stocks values compared to pasture sites (Cotching, 2012).

Therefore, carbon pools in soils can be improved through the following steps: efficient nutrients management, zero tillage farming, cover cropping, soil restoration and woodland regeneration, improved grazing, application of sludge and manure, water harvesting and conservation.

Dissolved organic carbon

This component of soil organic carbon basically comprised soluble parts of animal and plant residues. Incomplete decomposed soil organic carbon forms the particulate organic matter pool, consisting chiefly of debris. The roots of flora and fauna contribute to transportation and disintegration of soil organic materials. Particulate organic matter partly inhibits complete decomposition by microbes, hence, serves as an imperative continuing supply of nutrients (Wander, Traina, Stinner & Peters, 1994).

Humus

Humus controls numerous physicochemical properties linked to SOC and soil quality. Total SOC contains nearly 0.35-0.50 of humus, making it the largest constituent (Scientist *et al.*, 2017). Large quantity of humus in soils encourages high absorption of solar radiation resulting in increased temperatures in soils**.** Steady slow decomposition rate account for long time residence of humus in soils. As a result of humus' chemical make-up and reactivity, it predominantly determines soil's nutrients retention ability on conservation sites. Humus also provides organic chemicals to the soil solution that acts as chelates and intensifies availability of metal to plants (Scientist *et al.*, 2017).

Organic chemicals

Soil organic chemicals curtail the binding of phosphate with calcium, perhaps storing of mineral phosphorus solution for a longer period (Grossl & Inskeep, 1991). In addition, dissolved organic chemicals work to bind particles of soil in place, thereby accelerating their accumulation and increasing total soil ventilation, infiltration and retention of water, and resistance to both erosion and crusting.

Soil organic carbon storage

Quantifying potential SOC storage at the present time using apposite pointers could be preferable choice for accurate and precise detection of SOC through field and laboratory experimentations which are not time and cost effective (Wiesmeier *et al.*, 2013). According to Govers *et al.* (2013), there exist a relative strong agreement on total global quantity of SOC stocks; nevertheless, the apportionment of SOC stocks across dissimilar biomes is not clear.

Govers *et al.* (2013) indicated that soils can accumulate large proportions of SOC under very low decomposition rates. The main determinants of SOC stocks distribution are human intervention and natural phenomenon, hence, the global soil organic carbon distribution spatially is erratic (Govers *et al.*, 2013). Factors responsible for soil formation except time and the kind of management and use of land determine the quantum of SOC stored (Moni, Chabbi, Nunan, Rumpel, Chenu 2010; Manning *et al*., 2015).

Factors affecting soil organic carbon

Climate, nature and amount of clay fraction, and the kind of organic material largely determine SOC content (Verheijen, Bellamy, Kibblewhite & Gaunt, 2005; Maraseni *et al.*, 2008). Major changes in land uses brought about erratic disparity in the organic carbon levels of soils but the degree of changes lessen with the passage of time under a new management system (Janzen, Campbell, Ellert & Bremer,1997). Natural factors influencing soil organic carbon content include vegetation cover, parent material (Gray, Bishop & Yang, 2015), clay content and climate (Verheijen, Bellamy, Kibblewhite & Gaunt, 2005; Maraseni *et al.* (2008) whiles the anthropogenic determinants comprised organic inputs, land use types and management practices of soil. These disruptions break the dynamic stability of soil hence, resulting in emission of carbon dioxide into the air (Paustian, Six, Elliot & Hunt, 2000). A positive association exists between absorption capacity of atmospheric carbon and SOC. Hence, an increase in SOC content by 0.04% worldwide may compensate all the emissions and vice versa.

Despite these assertions, there are still doubts about the exact factors that regulate storage of SOC, key among them is climate (precipitation and temperature) (Hobley, Wilson, Wilkie, Gray & Koen, 2015). Other drivers of SOC storage such as parent material, topography, kind of land use and management are less considered in literature. Therefore, as a matter of fact, to effectively implement C trading schemes to help address climate change, it would be prudent for in depth comprehension and proper quantification of anticipated SOC contents across dissimilar environmental and land use combinations (Badgery *et al*., 2013; Fischedick *et al.*, 2014).

Parent material

The contribution of parent material (PM) on SOC stowage received numerous investigations from many scholars from local to international scales. Parent material principally controls mineralogy of soil, texture and fertility, which influence net primary production and stability of soil organic carbon (Gray *et al.*, 2016). Parent material and soil type are strongly correlated, and associated with SOC storage; although, Gray, Humphreys, and Deckers (2009) found a weak correlation between the two in their study to establish the association between environmental indicators and SOC worldwide. Also, works on SOC inventories at regional and local levels experiencing diverse climatic conditions revealed that PM negligibly contributes to variation in SOC distribution spatially (Wiesmeier *et al*., 2014; Hobley *et al*., 2015).

Contrary to the above assertions, Hobley *et al.* (2015) found that SOC stored in subsoil was essentially influenced by classes of PM. This corroborated Vasques, Grunwald, Comerford and Sickman (2010) findings where they noted clear impact of PM on SOC stocks.

In synchronizing the numerous diverging views observed by previous works on the influence of PM on SOC stocks across varied regions, climatic conditions and depths, it is necessary for this work to look at carbon content in a wider scope to improve accuracy and reliability of organic carbon estimation.

Topography

Topographic features control SOC through their influence on water accumulation and discharge, water flow paths, precipitation and so contribute meaningfully to erosion procedures. Wiesmeier *et al*. (2013) credited spatial variability of SOC among agricultural fields during a regional inventory to topographic wetness index, hence, accumulation of SOC in groundwater-affected soils. Runoff footpaths are the main generators of soil erosion and redistribution, have indirect principal influence on the SOC storage in dissimilar sites (Doetterl *et al*., 2016).

Grimm, Behrens, Marker and Elsenbeer (2008) equally observed that, working on small site, SOC variation is controlled by both regional terrain characteristics and local factors. Topographic features (characteristics) like aspect, curvature, and slope apparently regulate SOC storage within small scales less than 100 meters whiles position may seem relevant at larger scales beyond 100 meters (Hobley *et al*., 2015). Chaplot, Bouahom, and Valentin (2010) attributed significant proportion of SOC variation to slope gradient whiles Powers and Veldkamp (2005) attributed 27 per cent SOC variation to both direction and magnitude between paired forestsland and pastures to slope gradient. Despite these leading facts, the relevance of topographic-related influence on SOC storage is still uncertain. Topographic parameters become basically irrelevant when SOC stocks variability is assessed at larger scale.

Climate

The main drivers of climatic conditions controlling SOC storage, carbon input and decomposition at both sub-regional to international level are temperature and precipitation.

Precipitation controls net primary productivity (NPP) in varied land settings and the fixation of C into the soil. Again, development of SOC stabilizing mineral on the surfaces through intensive disintegration of PM under damp areas is favoured (Doetterl *et al*., 2015); this usually results in decrease in soil pH thus, reducing decomposition of organic carbon in soil (Meier & Leuschner, 2010). In dry or semi-arid environments, water restricts NPP as well as SOC storage input (Hobley, Baldock & Wilson, 2016).

However, adequate water-availability and low temperatures reduce the activities of microbes to a greater extent as compared to net primary production (Lützow, & Kögel-Knabner, 2009), hence, limiting SOC storage capacity. These patterns bring about low decomposition in moist areas; high SOC accumulation whiles the reverse is observed in the sub-Saharan regions with high temperatures.

Soil organic carbon stocks commonly increase in taciturn moist conditions but decline in warm and dry climates at global (Jobbágy & Jackson, 2000) and sub-regional (Hobley, Wilson, Wilkie, Gray & Koen, 2015; Gray *et al*., 2016) scale.

Though, many researchers reported an inverse linkage between climate and SOC stock in terms of depth, it is expedient to identify the controlling factors of SOC stabilization within the soil environment (Gray *et al*., 2016).

Vegetation type

Several researchers at both regional and continental scales have long-established that vegetation type has high influence over SOC accumulation as it controls the input of C and its decomposition in numerous climatic zones. Within dissimilar environments, climate ranges across the globe, expressively, diverse SOC stocks and depth disseminations have been found among different types of vegetative covers due to varied nature of C apportionment (Jobbágy & Jackson, 2000). Gray *et al*. (2016) found that vegetative cover principally regulates SOC in the upper layer but declines with depth. At the local level characterized by undeviating climate, land use and vegetation types strongly affect the level of SOC stocks.

Plant variety and functionality of composition affect SOC storage among various land use systems unlike spatial scales, especially in undisturbed grassland networks in semi-arid settings (Soussana *et al*., 2004). The impact of vegetation type on SOC has been credited to variations in the chemistry of crop residue, though molecular obstinacy of plant inputs is heavily tempered with environmental factors; nevertheless, little knowledge exists to affirm the importance of such inherent properties as controls on SOC over time (Lützow *et al*., 2006).

Cong *et al*. (2014) and Lange *et al*. (2014) reported a positive association between plant diversity and SOC accumulation. They attributed this relationship to higher root biomass caused by plants' definite functional traits. Build-up of acidic litter in the organic horizon may have accounted for comparatively higher SOC stocks in coniferous species in temperate climate (Schulp *et al*., 2008). Nonetheless, scientists reported insignificant variation of SOC stocks in a whole soil pit among varied types of woods (Vesterdal, Schmidt, Callesen, Nilsson & Gundersen, 2008).

Land use change

Information on land use is a very imperative pointer for SOC storage at both local and subcontinental level (Wiesmeier *et al*., 2019). Land use and/ or cover change presently poses environmental concerns (depletion of biodiversity, change in climate, and air, water and soil pollution) to humans (Ellis & Pontius, 2007). Land use change majorly account for variation in SOC (Viscarra Rossel *et al.*, 2014). Any change in land use can substantially alter the related characteristics of the source or sink of atmospheric CO_2 and other greenhouse gases (Poeplau & Don, 2013). Studying the relations between land use systems and variation of organic carbon stocks are vital for soil carbon management and sustainable land use. Land use change influences the quantity of carbon detained in plants cover and soil and therefore either promotes carbon retention by sequestering atmospheric carbon dioxide or emitting carbon dioxide (a greenhouse gas) into the atmosphere. Globally, agricultural soils have the potential in sequestering C by 16.09% annually (Lal & Follett, 2009). Right from the period people started cultivating on pieces of land for close to over 12,000 years now, soil organic carbon content equally began fluctuating in these landscapes. For example, since 1850, degraded soils have lost close to 91.81 % (44-537 Pg) of soil organic carbon through conversion of land for agriculture activities across the globe (Lal, 2001). A range of concerns about land uses and changes in cover on ecosystem, goods and services have been of keen interest. Prime among them are; soil degradation (Trimble & Crosson, 2000), influences on worldwide biotic diversity (Sala *et al.*, 2000) and the ability of biological systems to cater for the desires of man. For example, diminution of soil organic carbon pool led to an estimated loss of 78 Mt of carbon to the atmosphere (Lal, 2004a). Agricultural lands (soils) lost between 0.2-0.75 of their soil organic carbon pool worldwide (Lal, 2015). Changes in land use bring about changes in soil organic carbon stocks; on average, SOC increased by 53 per cent and 19 per cent when cropland was converted to secondary woodland and pasture respectively (Govers *et al.*, 2013).

Inadequate information exists in relation to the effects of managing pasture (grassland) on SOC content, due to inadequate data and substantial spatial variation of organic carbon content in soils under grassland as observed by Soussana *et al*. (2004). Despite less data on grassland management effects, Conant *et al.* (2001) and Soussana *et al.* (2004) found that grassland management practices substantially influence SOC storage in temperate grasslands. Globally, investigators observed that SOC accumulation rates range between 100 – 300, 10–30 g C m^{-2} year^{-1} and averagely by 2.4 for intensively managed pasture (grassland) (Ryals & Silver, 2013), abandoned agricultural lands for over many decades (Post & Kwon, 2000) and native cover (Zehetner, 2010) respectively. However, in intensively grazed fields dominated with C3 SOC depletes at a faster rate (McSherry & Ritchie, 2013).

The unprecedented conversion of forests (Coastal savanna vegetation) or grasslands for crop cultivation in several parts of the world has significantly and rapidly resulted in SOC stock reduction as noted first by Houghton *et al*. (1983). An exorbitant reduction in SOC pool amounting to sixty per cent in temperate soils and seventy-five per cent or more in tropical soils were observed when native lands were converted to agricultural bionetworks. Martin *et al*. (2011) and Meersmans *et al*. (2008) discovered that variation of SOC storage in a decreasing order; grassland > forest (Coastal savanna vegetation) > cropland. Conversion of grasslands or woodland (forest) for crop production causes a depletion of SOC between 0.3-0.80 (Guo & Gifford, 2002; Wei *et al.*, 2014). Similarly, Guo and Gifford (2002) reported that when woodland (forest) is replaced with arable land, SOC stocks decline by 0.4 in soils. They noted an average drop in soil organic carbon by forty-two per cent and fifty-nine per cent corresponding to the conversion of woodlands to cropland and from pastures to cropping fields. The diminution of SOC stocks trend is aggravated where soils are severely degraded as well as where carbon input is less than output. Carbon lost through emission into the atmosphere from certain soils ranges between 20-80 tons of carbon per hectare.

A significant diminution of SOC pool give rise to decline in quality of soil, diminishes biomass productivity and unfavourably affects the quality of water, and further declination will exacerbate anticipated global warming. Decline in soil quality due to low-input of C in arable system averagely decreases yield by thirty per cent in organic agricultural sector (Seufert *et al*., 2012).

A consistent increase of atmospheric carbon dioxide between 800 BP-1000 BP was approximately 8 % (260-280 ppm) due to the early clearance of forest and subsequent emission of carbon from soil into the atmosphere (Ruddiman, 2003).

Finally, changes in land covers caused greater depletion of close to 75 % (108-188 Pg C) of SOC to the atmosphere (Pongratz *et al*., 2009; Eglin *et al.* 2010). In general, detail work is imperative for elucidating the range of influential factors controlling SOC levels (Gray *et al.*, 2016). Marland *et al.* (2007) also advocated for long-term studies on carbon stock for monitoring the dynamics of SOC distribution within various land use types.

Relationship between soil depth and organic carbon levels

An inverse relationship between SOC and depth under varied climatic settings was observed (Gray *et al.*, 2016). Substantial quantity of carbon stocks is confined within 0 to 30 cm (topsoil) in moist (wet) climate whereas similar amount is stored within the 30 to 100 cm (subsoil) in dry climatic zones. In Gray *et al.* (2016) observation of SOC stocks, moist climate witnessed a mean value of 0.41 as against 0.59 in dry climate; hence, climate is seen as a key dictator than the influence of vegetative cover and parent material. In a comparative analysis of SOC trend between different plantation species and native vegetative cover, 0 to 10 cm depth recorded high concentration of SOC in all the observed land use types and decreased relatively to the 100 cm depth; thus, a variation in SOC concentration were 0.034 and 0.102 in soil under the native vegetative cover and plantation fields respectively (Demessie *et al.*, 2011; 2012).

In addition, Singh, Wele and Lal (2010) in their study on the status of SOC and the rate of changes in the chronosequences assessment asserted that, 0-20 cm (topsoil) contained higher concentration of SOC as well as in native woodland with non-significant concentration of SOC in agricultural and agroforestry lands. Similar trends showed in a study conducted to examine soil carbon sequestration ability of cropped fields to agroforestry in chronosequences where traditional agroforestry recorded high SOC stocks than cropped lands in all chronosequences. Depth of soils, for example, subsoil layers contribute to about 2/3 of global carbon sink (Jobbágy & Jackson, 2000). Organic carbon content in subsoil increases with depth and time owing to surface dissolution and under accumulation (Schmidt *et al.*, 2011). Many Researchers focused on SOC storage within the topsoil, nonetheless, the role of sub-soil in SOC storage cannot be underestimated (Cotching, 2012). Soil organic carbon stocks found within 0-30 cm layer were 16.3 Mg ha^{-1} and 145.0 Mg ha^{-1} dry (highly silica dominated parent material environments within low vegetative cover) and wet environments (parent material environments within high plants cover) respectively but however ranged between 18.7 to 106.1 Mg ha^{-1} at 30-100 cm layer (subsoil) under varied eco-friendly settings (Gray *et al.*, 2016). Globally, the amount of SOC stored within the topsoil nearly equals to thrice of carbon in aboveground undergrowth as well as two times of that in atmospheric CO_2 (Batjes, 2001; Lal, 2004).

Again, at the continental level, it is estimated that, almost 75 per cent of SOC stocks contained within the upper meter (0-1 m) are confined to 0-30 cm layer (Liu *et al.*, 2013). Intensive cultivation exposes topsoil of newly discovered lands to the elements of degradation and consequently altering the landscape's natural ecological conservatory equilibria (Senjobi & Ogunkunle, 2010). Hence, tropical soils that are usually less stable than those of the temperate climates, are significantly severely vulnerable, because of their fragile properties and therefore, the terribly aggressive climate. It is calculable that thirty-eight per cent of lands under cultivation have been degraded worldwide. Annually, approximately 9.6 million hectares of land suffer from surface soil losses equating to twenty-four billion tons (Nanganoa *et al.*, 2019). Topsoils (0-30 cm depth) are mostly susceptible to modifications fuelled by disturbance and extreme events, management practices, changes in climate and land use and cover change. Degryze *et al.* (2004) discovered that at 0-7 cm layer, native vegetative cover used for cultivation lost close to 30-35 cm of its carbon within the first 30 years of continuous cultivation while no changes were recognized for depth below plough level.

Influence of individual factors driving soc variation with depth

Climate

Globally, influence of climate as a key determinant of SOC stock beyond local, sub-regional and regional levels is known. Climate predominantly controls organic matter production, its extent of mineralization and its ensuing depletion from soils containing high levels of SOC under cool moist situations (Cotching, 2012; Badgery *et al.*, 2013). Temperature and precipitation are the key climatic elements controlling SOC retention. For instance, Gray *et al.* (2016) study confirmed Bui (2012) and Wang, Su, and Yang (2014) work which established that the influence of temperature at 0-15 cm depth (near surface) is more important as compared to precipitation whiles precipitation becomes more influential at 15-30 cm depth (deeper level) resulting in negligible influence of temperature as depth increases to a certain level. Though, precipitation influences SOC levels at deeper depths, it becomes less important beyond 30 cm (> 30 cm) depth (Gray *et al.*, 2016). In general, there is both direct and inverse linkage between climate and SOC levels at various soil depths.

Parent material

Soil type is closely defined by parent material (PM) and has been unanimously known to have a key control on the amount of SOC (Cotching, 2012). Principally, PM controls SOC because of its defining role over soil texture (clay fraction) that act to shield SOC from being mineralized (Heckman, Welty-Bernard, Rasmussen & Schwartz, 2009); its influence on fertility of soils and supply of nutrients to plants for increased biomass (Badgery *et al.*, 2013).

The essentiality of PM as a chief determinant of SOC content internationally cannot be underestimated and has been widely studied recently by many researchers (Viscarra Rossel *et al*.., 2014). Parent material has become the clearly dominant regulator of SOC at near surface, in the mid and lower layers (Gray *et al.*, 2016).

Land use

Land use though affects SOC contents, it becomes little of importance with increasing depth. The impact of land use seems to decrease exponentially with increasing depth (Badgery *et al*., 2013). Wilson and Lonergan (2013) also discovered that land use types have little influence on the vertical distribution of SOC.

Though many asserted that land use has little control over SOC at soil depth, it is still very noteworthy for the projection of carbon in subsoils (Rumpel & Kögel-Knabner, 2011). For instance, Cotching (2012) accredited land use as an imperative regulator of these reasonable amounts of SOC storage in soils.

In summary, at 0-30 cm interval (upper depth), the significance of environmental and land use factors can be ranked relatively as vegetation cover/ land use ≈ topography < parent material < precipitation < temperature whereas at 30-100 cm interval (deeper depths), these influences seemed to be ranked as topography ≈ temperature ≈ vegetation cover/ land use < precipitation < PM (Gray *et al*., 2016). Considering soil in totality on the other hand, Baldock and Skjemstad (1999) ranked land management, chief influential element and composition of soil mineralogy being least of all.

Decisively, Gray *et al*. (2016) ranking indicated negligible relevance of climate, explicitly temperature, with depth and parent material being principal element, paralleling observations made by others (Hobley *et al*., 2015).

Influence of combined factors of SOC storage in relation to soil depth

Organic carbon stored in soils across diverse regions with respect to dissimilar climate, type of soil and land use lay the foundation for the concept of "carbon zone" (Murphy, Wilson, & Rawson, 2010) and the "potential capability index" (Baldock *et al*., 2009). Individual factors broadly affect SOC at varied degrees of significance and when combined together will help control final SOC stocks (Gray *et al*., 2015).

Elucidating and deriving meaningful estimation of potential SOC storage levels, the combined influence of the main elements of soil formation needs to be noted as necessities (Gray *et al*., 2016). Climate strongly influences proportion of SOC stored within subsoils especially, in drier climates where large quantities of SOC storage are confined to subsoils against what is found in upper meter soil which can possibly be influenced by vegetative cover and PM in more complex trends (Gray *el al*., 2016). Any current estimate or future projection of SOC stocks can only be reliable when full attention is given to the key controlling factors together. Internationally, the differing SOC storage potential of diverse types of soil have been severally recognized and discussed (Eswaran *et al*., 2000; Lal, 2004a).

In a nutshell, knowing the influence of combining the multidimensional factors can serve as a guide for identifying soil-environment regimes that can be prioritised in C retention programmes. Again, knowing the status of SOC levels is crucial for effective formation and process of C trading systems as a means of mitigating climate change (Gray *et al*., 2016). Despite the countless importance OC plays in ensuring sustainable agriculture, environmental quality and climate change mitigation per dozens of literatures reviewed and hundreds of field studies conducted, qualms still exist regarding how land use systems determine the distribution of SOC globally, especially in Ghana. The extent to which land use systems influence land degradation have equally not been totally ascertained within several of parts of Ghana (particularly in UCC farm). And information on the consequences of land management on the quantity of SOC and alternative soil physico-chemical properties in different land uses or practices in Ghana is still scanty and so makes it tough to advocate for adoption of applicable conservation and proper land management practices.

CHAPTER THREE

MATERIALS AND METHODS

Study area

The study was conducted at the University of Cape Coast Teaching and Research Farm, Central Region of Ghana. The site covering 24.5 ha of land lies within the Coastal Savanna zone dominated by shrub and thicket vegetation (Figure 1).

The study site lies between Latitude 5º 06'N and Longitude 01º 15'W, experiences biannual (major and minor) raining seasons. Averagely, the major rainy season with an average rainfall of 153 mm commences in March and ends in July whiles the minor season with an average rainfall of 114 mm commences from September and ends in December in each year. Variation in monthly rainfall ranges between 25 mm and 229 mm, though, monthly variation between the wettest and driest months is 204 mm. The mean high temperatures and low temperatures recorded in the region are 32 ^{0}C in January and 26 ^{0}C in September respectively.

The soils are principally made up of shales, sandstones and conglomerates of Devonian age originated from Sekondian rocks. The soil is generally acidic due to leaching of its bases resulted from extreme weathering. Low activity kaolinite clays and sesquioxides dominate soils of the study site (Asamoa, 1973).

The selection of these dominant land use types was due to the fact that some of the uses might have resulted in depletion of SOC levels. The depletion of SOC may lead to land degradation, low agricultural productivity and exacerbate climate change through human influences (Cotching *et al*., 2013).

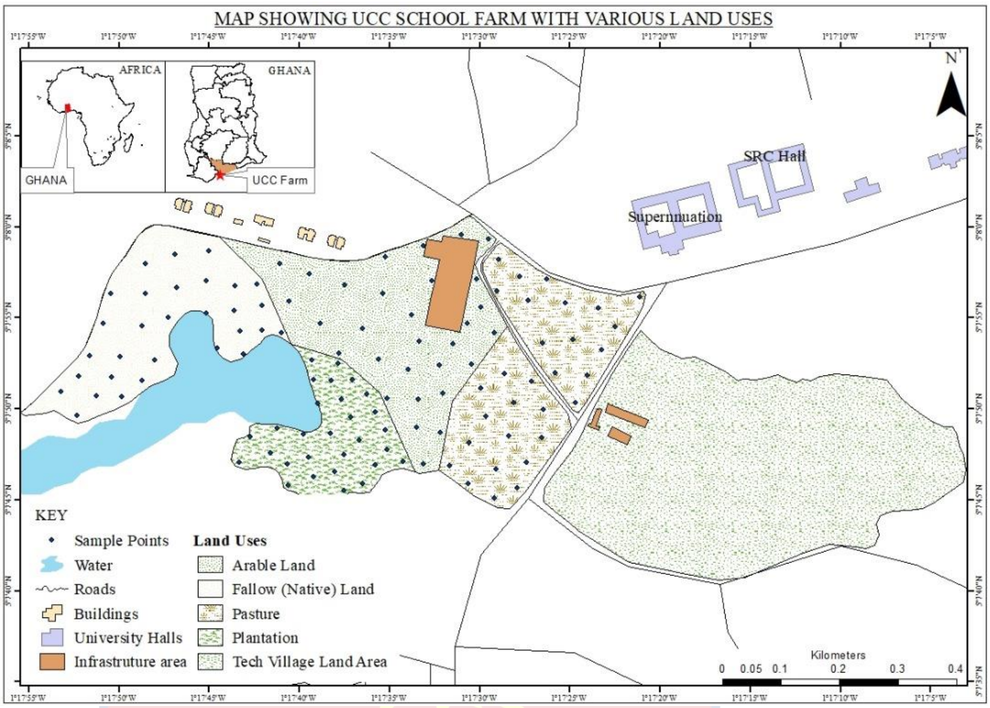

Figure 1: Map of study site showing sampling points in each land use type

Field Characteristics

Land use history

The University of Cape Coast Teaching and Research Farm, established in 1975 had as its objective of provision of food requirement for the University's Community in respect of farm products: vegetables and meat products. Population growth coupled with changes in demand for food brought about a considerable change in the farm due to intensive cultivation practices for the past decades. The study area comprised four dominant land use types (fallow, plantation, arable and grazing land). Agricultural activities are mainly rain fed. However, during drought periods, the arable crops are usually supplemented with irrigation through sprinkling. The observed cropping systems since the establishment of the farm include mono-cropping, mixed-cropping amidst soil management practices. The latter includes manuring and occasional pesticides and inorganic fertilizers application.

Part of the farm has been cropped to oil palm and coconuts which serve as the dominant cash crops (plantation) grown for over four decades now. In the plantation, soil conservation practices included non-removal of cleared weed and litter fall.

The arable land has been in operation since 1975. The crops cultivated include maize, cassava and vegetable crops such as garden eggs, lettuce, carrot, okro, ginger, cowpea, cabbage and pepper.

Soil management practices include zero, minimum and deep tillage system. Deep tillage is intensively practised in parts used by students for their projects. The soil amendment practices have been green manuring, application of manure and inorganic fertilizers and burning/ removable of crop residue and cleared weeds prior to planting.

The management practices in the pasture and fallow lands included zero tillage, non-removal of litter falls and no evidence of organic and inorganic fertilizer applications.

Field work

A preliminary survey was conducted purposely for the identification and demarcation of the various major land use types within the field. The land use history of the farm was obtained from the farm Manager through an official visit in his office.

Garmin eTrex 30x GPS device was used for recording coordinates of the study area and each land use type’s boundaries and saved on the device (receiver) at the time of the fieldwork.

The site was then properly segregated into different land uses taking into consideration, the major land cover and history of usage of these fields. Arable, plantation and pasture have been in operation since 1975 with the exception of the fallow which has been fallowed for about 15 years now.

Land use types: Four types of agricultural land uses were selected for the study: pasture, plantation, arable and fallow (abandoned) lands. 'Pasture land by definition refers to sites that have been devoted to the growing of pastures for not less than eight years; whereas 'arable (cropping) lands' include sites that have been cropped for five or more years, 'plantation' which required large parcels of land has to be in operation for a minimum of five years and 'fallow (abandoned) land' for 10 or more years of non-cultivation.

Field sampling

The type of soil, depth, physical features and management practices of the site were equally observed. During soil sampling, tillage practices, history of soil fertilization (soil amendment practices), patterns of cropping, the type of soil as well as the characteristics of slope and drainage and borders of the field were taken into considered.

Sampling method

Selection of a sampling unit

Selection of the sample size and sampling locations took into consideration the true representativeness and variation in texture, colour, slope, land use and management history and pattern of crops cultivated in the field during visual survey of the field. The field was demarcated according to the major land use types.

Soil sampling technique

Each land use type was properly demarcated where grids were constructed. A baseline was constructed and perpendicular lines drawn at 10 m parallel to the baseline to run through each site.

A stratified random sampling technique was used for soil sampling where GPS coordinates were recorded alongside at each sampling point. The four (4) strata (land use types) were demarcated and five (5) mini pits, each measuring 1 m × 1 m × 50 cm were randomly dug and marked at 0-15 cm, 15-30 cm and 30-45 cm depths on each land use type. At each soil depth, 3 soil samples were randomly collected in a zigzag pattern, given a total of 60 samples (3 samples x 5 pits x 4 land use types). A total of 180 samples were collected at the 3 depths across the entire field for the vertical distribution of soil properties. The top soil depth (0-15 cm) samples of 60 were again used for the determination of the spatial soil properties variation.

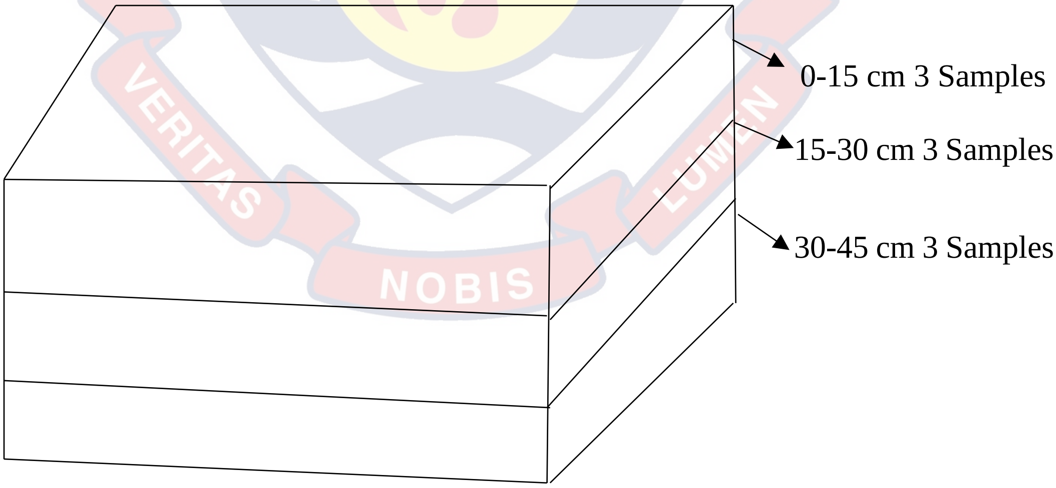

Figure 2: Sketch of sampling technique in one stratum (Mini pit)

Sample preparation

Samples were air-dried and taken to the laboratory analysis. However, for moisture content and bulk density separate samples collected with Core

Samplers were immediately sent to the laboratory for determination. Plant materials and clods were removed from soil before samples were crushed using a mortar with pestle. Soils were sieved using a 2 mm mesh sieve, where fine earth obtained was put into labelled transparent plastic zip lock bags and sealed.

Laboratory analysis

At the laboratory physical and chemical analyses were performed according to standard laboratory methods (Shepherd & Walsh, 2002). The physical properties analysed included bulk density, moisture content and particle size distribution while the chemical properties were pH, total nitrogen, available phosphorus, SOC, exchangeable acidity and exchangeable cations.

Measurement of Soil Physical Properties

Determination of moisture content

Gravimetric technique was used to determine the moisture content of the soil.

Empty ovenproof beakers were cleaned, dried at 105 ^{0}C in an oven, labelled and weighed (M_1) on an electric weighing scale.

Each fresh core soil sampled from the field were carefully poured into the empty weighed beakers and recorded (M_2). The beakers containing soil content were dried at a temperature reading 105 °C for about 24 hours to dry to constant weight and then kept in a desiccator for about 30 minutes to cool before weighing. The new weight of beakers with their contents (oven-dry samples) were weighed and recorded (M_3).

The soil moisture content (M_w) was then computed as a percentage of the dry soil as:

$$\text{\% Soil Moisture by weight } (M_w) = \frac{M2-M3}{M3-M1}\ x\ 100$$

Where:

M_1 = Empty beaker's weight of (g)

M_2 = Weight of moist soil + beaker (g)

M_3 = Weight of dried soil + beaker (g).

Moisture content was reported to the nearest 0.1 per cent.

Determination of bulk density

Core samplers of radius (r) 2.5 cm and height (h) of 15 cm were used throughout. Soil core samples were collected from various mini pits at each depth. Core samplers were hammered into the soil cautiously to prevent compaction by hitting the outer holder cylinder holding the core samplers with a rubber hammer till the cylinder was fully filled with soil. The outer holder cylinder holding the 15 cm aluminium core sampler containing soil was removed. Buried sampler was excavated and trimmed from the bottom until soil was flushed with the rim of the outer holder cylinder.

Next, all the soil samples were kept in the transparent zip lock bags and sent to the laboratory. At the laboratory, cleaned and dried empty beakers were weighed (W_1) and core samples were then poured into these beakers and dried in an oven at a temperature of 105 °C for 24 hours. Dried soil samples were then weighed and recorded (W_2).

The bulk density (Db) of soil was determined as prescribed in core method proposed by Grossman and Reinsch (2002) and ASTMD 2937-83 (The American Standard Test Method for Density of Soil in Place) (Anderson & Ingram, 1993).

The bulk density of the soil at various depths were calculated as follows (Cresswell & Hamilton, 2002; Zhou *et al*., 2006).

Weight of dried soil (W_3) = $W_2 – W_1$

Dry Bulk density (Db) in g cm^{-3} is given by: = [weight of dried soil (W3) in g / volume of soil (V) in cm^3]

Bulk density (g cm^{-3}) =$\frac{W3\ (g)}{V\ (cm3)}$

Where;

V= the volume of core samplers (cm^3)

which was calculated as $V=\pi r^2h$; hence, π = 3.142, r = radius of core = 2.5 cm, h = height of core = 5 cm,

W1= soil weighed freshly and W2= oven-dried weight of soil.

Net weight (g)= W_1-W_2

Soil texture

Determination of particle size distribution

The particle size distribution of the soil was determined by pipette method (Rowell, 2014). Samples of soil were sieved using a 2 mm sieve shaker. About 50 ± 0.05 g of fine earth was kept in a 500 mL heat resistant beaker and 20 mL of 30%H_2O_2 was used to remove organic matter while the fine earth dispersed with 10 ml Calgon solution. About 125 mL of water was then added to the peroxide-treated soil in the beaker and swirled to wet fully. About 20 mL of 30% hydrogen peroxide was added to the beaker and swirled gently but where foaming was noticed, drops of amyl alcohol was added and gently swirled to minimize it and allowed to cool. The suspension was further topped up with 200 mL of distilled water and shaken overnight. The content was now transferred into a litre measuring cylinder and 500 mL of distilled water added. The content was stirred with a plunger to ensure thorough mixing. The suspension was allowed to settle for about 40 seconds and 25 mL of the suspension was pipetted from 10 cm below the surface into weighed beaker. The suspension pipetted represented the mass of silt and clay. The content was left undisturbed for about 6 hours 40 minutes and another 25 mL suspension was pipetted off at 10 cm from the surface into weighed beaker. This also represented the mass of clay only. The two consecutive suspensions pipetted were dried at 105 ^{0}C till constant weights were obtained. The remaining dried soil was passed through a 0.3 mm sieve, which was placed above a 500 ml sedimentation cylinder with a stand and a clamp. The sand fraction remaining in the sieve was quantitatively washed into a 50 mL beaker of known weight and together with the other beakers dried overnight in an oven at 105 ^{o}C. After drying the contents of each beaker were cooled in a desiccator and weighed and the weight of the empty beaker was subtracted from the new weights to obtain the weight of sand and other weights for the purpose of calculation.

$$\% \text{ Sand (m/m)} = \frac{\text{mass of sand}}{\text{mass of oven dry soil}} \text{ x } 100$$

$$\text{The total mass of silt in the soil sample} = \text{mass of silt in } \frac{25 \text{ mL } x \text{ } 500}{25}$$

$$\% \, Silt = \frac{\text{total silt}}{\text{mass of oven dry soil}} \text{ X } 100$$

$$\text{The total mass of clay in the soil sample} = \text{mass of clay in } \frac{25 \text{ mL } x \text{ } 500}{25}$$

$$\% \, Clay = \frac{\text{total clay}}{\text{mass of oven dry soil}} \text{ x } 100$$

The Textural Triangle of USDA system was used for textural class determination after calculating the per cent soil fraction (Rowell, 2014).

Measurements of Soil Chemical Properties

The soil chemical properties analysed were total nitrogen, available phosphorous, exchangeable potassium, exchangeable aluminium, cation exchange capacity, pH and organic carbon

Determination of total nitrogen

Total nitrogen in the soil was determined by the Semimicro-Kjeldahl oxidation method (Haynes, 2000). This involved digestion of 0.5 g of soil sample at 360 °C for 2 hours with a digestion mixture (selenium powder, lithium sulphate, hydrogen peroxide and concentrated sulphuric acid) followed by steam distillation and titrated with M/140 HCI.

The digestion blanks treated in the same manner were subtracted from the sample titre value. The nitrogen was calculated with the formula below:

$$\text{N }(\%) = \frac{(\text{S}-\text{B})\times \text{solution volume}}{10^2 \times aliquot \times sample\ weight}$$

Where,

S= Sample titre value

B= Blank tire value

Determination of available phosphorus

Bray No. 1 method was used to determine the available Phosphorus (Bray & Kurtz, 1945). Extracting solution of 10 ml was added to a 15 ml centrifuge tube containing one gram of soil sample. The content was then shaken for 5 minutes and filtered through Whatman No. 1 filter paper into beakers. Two millilitres aliquot of the extract was pipetted into 25 ml volumetric flasks. About 100 ml 5 µg P / ml was prepared from the stock solution of P for each sample or filtrate. A set of working standards of P containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 µg P ml^{-1} were prepared from the 5 µg P ml^{-1} solution and transferred into 25ml volumetric flasks. The same volume of the extracting solution for both blank and P standard was used for the soil P test. Each flask containing 10 ml of distilled water were topped with 4 ml of reagent B to make up to volume with distilled water. The absorbances were determined on a spectrophotometer at 882 nm after the colours were allowed to develop for 15 minutes.

Available P was thus calculated as:

If C = µg P ml^{-1} obtained from the graph, then,

µg P g $soil^{-1}$ = C × dilution factor.

Available phosphorous in mg kg^{-1} is given by:

$$P = \frac{C \times 50}{Ws}$$

Where,

C = concentration derived from the standard curve

Ws = weight of soil sample

50 = dilution factor (vol. Extract/ vol. Aliquot)

Determination of exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+})

Analyses of the exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) was done following Anderson and Ingram (1993) method.

A 20 mL of ammonium acetate solution was added to a 100 ml extraction bottle containing five grams of fine earth, stirred and allowed to stand overnight. A filter paper fitted in a filter funnel was used to filter the suspension into a volumetric flask measuring 100 mL. The soil was leached with successive 20 mL volume of ammonium acetate where the funnel was allowed to drain completely between each addition. This was continued until the 100 mL of filtrate collected and topped up to the mark with ammonium acetate. An aliquot of the extract was used to determine Ca^{2+}, Mg^{2+} and K^{+}.

Determination of exchangeable potassium

Working standard of 0, 2, 4, 6, 8, 10 uP mL^{-1} of K^{+} in ammonium acetate solution. The working standards were aspirated into a flame photometer and the readings recorded. The soil extracts were aspirated and their emissions recorded. The standards and their emissions were used for plotting the calibration curve where K^{+} concentration in the extracts was obtained.

Determination of exchangeable calcium and magnesium

Sum of exchangeable calcium and exchangeable magnesium (Ca^{2+}, Mg^{2+}) was determined together using solochrome black indicator and the difference in titre values between $\sum (Ca^{2+}, Mg^{2+})$ and Ca^{2+} alone was used for calculating exchangeable magnesium (Rowell, 1994).

Conical flask measuring two hundred and fifty mL containing 25 mL aliquote of the extract was diluted with distilled water to one hundred and fifty mL. About 15 mL of buffer solution and ten drops of each of KCN, $NH_2OH.HCl$, $K_4Fe(CN)_6$ and triethanolamine (TEA) were added and allowed for few minutes for the reaction to take place. Ten drops of Erichhrome Black T (EBT) for the titration of the solution with 0.005 M EDTA to a blue.

Exchangeable calcium determination

About 150 mL of distilled water was used to dilute an extract of 25 mL aliquot content in a 250 mL conical flask. Ten drops each of KCN, NH_2OH HCl and triethanolamine, and enough 10 % NaOH were added to it to raise the pH to 12 or slightly higher. Five drops of calcon indicator were added and the solution titrated with 0.005 M EDTA from red to blue end point.

Exchangeable magnesium determination

An aliquot of 25 mL of the extract was poured into a 250 mL beaker and diluted with distilled water to a total volume of about 100 mL. About 20 mL of 20 % tungstate solution and enough buffer solution to increase the pH value to 10. Whatman no. 42 filter paper was used to filter the heated solution. A solution containing 50 mL of buffer solution per litre was used to clean or wash the paper and the precipitate. Ten drops each of KCN, $NH_2OH.HCl$, $K_4Fe(CN)_6$ and triethanolamine (TEA) was added to the filtrate and allowed for few minutes for the reactions to take place. The solution was titrated from a red to a permanent blue colour by adding 10 drops of EBT indicator.

Exchangeable acidity determination

Ten grams of dried soil samples and 30 mL of 1 M KCl were put in a beaker overnight. The suspension was leached into a 100 mL volumetric flash and increased to the mark with successive 10 mL volume of KCl.

Exchangeable acidity

Five drops of phenolphthalein indicator were added to 50 mL of the KCl extract pipetted into a 250 mL conical flask. 0.01M NaOH was used to titrate to the appearance of a pink colour. This measures the exchangeable $H^+ + Al^{3+}$.

The exchangeable cations (K^+, Ca^{2+} and Mg^{2+}) and the exchangeable acidity ($H^+ + Al^{3+}$) were calculated as:

$$\text{cmol}_c\ K^+\ kg^{-1}\ \text{soil} = \frac{C \times 10}{wt \times 39.1}$$

$$\text{cmol}_c\ Ca^{2+}\ kg^{-1}\ \text{soil} = \frac{C \times 10}{wt}$$

$$\text{cmol}_c\ Mg^{2+}\ kg^{-1}\ \text{soil} = \frac{C \times 10}{wt}$$

$$\text{cmol}_c\ H^+ + Al^{3+}\ kg^{-1}\ \text{soil} = \frac{2 \times T}{wt}$$

where,

C = concentration of extract from standard curve.

10= factor

2= Factor

Wt = weight of soil

39.1= Molar mass of potassium

T= Titre values of respective cations

Determination of organic carbon

About 0.5 g of soil was poured into a ceramic cup where few drops of 1M HCL discharged onto the sample. Mineral carbonates present was determined through conspicuous effervescence (Cotching *et al.*, 2013).

Walkley and Black (1934) wet combustion procedure was then used to determine the SOC. Duplicates of 0.5 g soil samples kept in 500 mL Erlenmeyer flask where 10 mL of potassium dichromate ($K_2Cr_2O_7$) solution was pipetted into each flask and swirled gently. About 20 mL conc. sulphuric acid (H_2SO_4) was again added and swirled gently for a minute and the flasks were left undisturbed for half an hour. The addition of conc. H_2SO_4 was to generate heat that was required to drive the reaction to completion. About 200 mL of distilled water was used to dilute the flask containing the content and swirled again to ensure thorough mixing after it stood for 30 minutes undisturbed. About 10 mL of H_3PO_4, 0.2 g NaF and 1 mL of diphenyamine indicator were also added. H_3PO_4, and NaF were added to complex Fe^{3+} which could have interfered with the end point. Excess Cr_2O_7 was back titrated with 0.5M ferrous solution to a green end point.

Finally, a blank titration was also carried out in the same manner using the same reagents but without the soil. Per cent organic carbon (% C) was calculated with the formula below:

$$\text{\% Organic carbon} = \frac{(\text{B-S})\times\text{Molarity of }\times\text{Fe}^{2+\,\times\,0.003}}{\text{weight of soil}}\times\frac{100}{77}\times 100$$

B = Blank titre value

S = Sample titre value

M of Fe^{2+} = molarity of ferrous sulphate solution for blank titration Wt = soil weight (g)

0.003 = 12 / 400 = milliequivalent weight of C in gram

100/77 = the factor converting the carbon actually oxidized to total carbon

100 = the factor to change from decimal to per cent

Determination of soil pH

Soil pH was determined using 2:5 of soil-water ratio (Black, 1965) using a digital Hanna pH meter instrument with serial number 673597. Three buffer solutions prepared at pH 4.00, 7.00 and 10.00 were used to calibrate the meter where the pH electrode was inserted in the beakers containing these solutions alternatively and pH meter adjusted for samples to be tested.

About 10 ± 0.1 grams of soil were placed in bottles with screw caps and 25 ml of distilled water measured from a measuring cylinder was poured into the bottles containing the soil samples. The bottles were then placed in a shaking machine and shaken for 15 minutes.

Finally, Hanna pH electrode injected in the suspensions and the stabilised readings of pH values from the screen documented. The electrode was rinsed in distilled and wiped with tissue paper after each successive reading. An average of the pH readings recorded were computed and used as the final pH for the various land use systems.

Data analyses

Map of the study site and spatial distribution and concentration of soil properties at various depths were generated using Kriging in ArcGIS 10.5 software. Descriptive statistics of soil parameters at soil depths and among land use types in summary tables were generated using analysis of variance (ANOVA) in Minitab version 19. The data were checked for normality of variances of means of soil properties and relationships between SOC and other properties at soil depths and land use types using Anderson-Darling and Ryan-Joiner in Minitab version 19 respectively to meet the assumptions of ANOVA. Fisher Pairwise Comparisons at 95% Confidence method in Minitab was also used to assess the mean difference of soil properties among the land use types and soil depths at 95 % confidence level. Relationships between SOC and the other physicochemical properties at soil depths and land use types respectively were performed using Pairwise Pearson Correlation in Minitab. The level of association between SOC and other soil properties across soil depths and land use types using Pairwise Pearson Correlations were tested for significance using $p < 0.05$ as a criterion for significance.

CHAPTER FOUR

RESULTS

Introduction

Generally, soil property in each land use type changed with soil depths. The vertical distribution of most soil properties differed significantly ($p < 0.05$) with soil depths within each land use type (Table 1 and 2). About 60 % of these properties decreased with depth (Table 1 and 2). This means that most of these properties were highly concentrated at surface depth.

Conversely, there was statistical difference in the mean distribution of all the properties in each land use type (Table 3 and 4). About 54 % of these properties including NPK were highly concentrated in the arable relative to other land use types. Moreover, plantation retained the highest SOC.

Soil Physical properties

Descriptive statistics of physical properties (Appendix A1) shown that bulk density, texture and moisture content ranged between low to high variability with coefficient of variation ranging from 6.2 to 34.80 %. Among the physical properties studied, clay was found to be highly variable (CV = 34.8 %) at 30-45 cm depth while bulk density had the least variability (CV = 6.2%) at 15-30 cm depth.

Table 1: Mean vertical distribution of soil physical properties among land use types

Soil	Depth	Land Use Types			
Properties	**(cm)**	**Arable**	**Fallow**	**Pasture**	**Plantation**
Bulk density	0-15	1.14±0.12^{c}	1.02±0.23^{a}	1.20±0.12^{b}	0.98±0.13^{b}
(g cm^{-3})	15-30	1.03±0.15^{a}	1.14±0.19^{b}	1.11±0.14^{a}	0.90±0.14^{a}
	30-45	1.10±0.13^{b}	1.09±0.21^{b}	1.17±0.11^{b}	0.96±0.14^{b}
Moisture	0-15	15±40.07^{a}	17.38±6.93^{a}	14.76±3.36^{a}	18.72±3.39^{a}
Content (%)	15-30	15.19±4.06^{a}	15.82±5.03^{b}	14.93±3.41^{a}	18.61±3.34^{a}
	30-45	15.19±3.80^{a}	15.68±4.80a^{b}	14.99±3.51^{a}	18.72±3.73^{a}
Sand (%)	0-15	61.02±2.96^{a}	41.69±2.80^{a}	42.26±3.02^{a}	31.93±30^{a}
	15-30	60.48±2.69^{a}	41.43±2.73^{a}	41.73±2.71^{a}	31.38±2.81^{a}
	30-45	60.51±2.76^{a}	41.15±2.86^{a}	41.74±2.75^{a}	31.61±3.12^{a}
Silt (%)	0-15	12.88±3.40^{a}	18.83±3.28^{a}	14.66±3.28^{a}	21.81±3.26^{a}
	15-30	14.43±3.48^{b}	20.36±3.33^{b}	16.4±3.30^{b}	23.64±3.73^{b}
	30-45	13.36±2.90^{a}	19.45±2.83a^{b}	15.24±2.28^{a}	22.55±3.11^{a}
Clay (%)	0-15	26.10±4.30^{a}	39.47±4.15^{b}	43.06±4.32^{b}	46.24±4.40^{a}
	15-30	25.09±3.62^{a}	38.20±3.39^{a}	41.87±3.45^{a}	44.97±3.77^{a}
	30-45	26.11±3.25^{a}	39.39±3.21^{b}	43.02±3.25^{b}	45.84±3.60^{a}

Means that do not share a letter are significantly different ($p \leq 0.05$).

Table 2: Mean vertical distribution of soil chemical properties among land use types

Soil Properties	**Depth (cm)**	**Land Use Types**			
		Arable	**Fallow**	**Pasture**	**Plantation**
OC (%)	0-15	2.23±0.40^{c}	1.31±0.24^{c}	1.47±0.23^{c}	2.57±0.25^{c}
	15-30	2.0±0.51^{b}	1.23±0.25^{b}	1.26±0.36^{b}	2.32±0.47^{b}
	30-45	1.63±0.37^{a}	0.89±0.30^{a}	0.91±0.26^{a}	1.98±0.38^{a}
N (%)	0-15	0.2±0.10^{a}	0.13±0.10^{a}	0.12±0.04^{a}	0.2±0.10^{a}
	15-30	0.19±0.08^{a}	0.12±0.07^{a}	0.13±0.04^{a}	0.2±0.14^{a}
	30-45	0.18±0.07^{a}	0.11±0.07^{a}	0.11±0.06^{a}	0.19±0.13^{a}
AP (Mg kg^{-1})	0-15	10.21±1.58^{b}	3.70±1.72^{b}	5.36±1.94^{b}	3.21±1.43^{b}
	15-30	9.30±1.70^{a}	2.91±1.41^{a}	4.44±1.97^{a}	2.56±1.33^{a}
	30-45	9.16±1.66^{a}	2.62±1.4^{a}	4.38±1.95^{a}	2.49±1.42^{a}
pH (2:5)	0-15	5.35±0.19^{b}	4.57±0.26^{b}	5.31±0.19^{b}	5.35±0.19^{b}
	15-30	5.32±0.23^{b}	4.51±028^{b}	5.26±0.23^{b}	5.31±0.24^{ab}
	30-45	5.22±0.39^{a}	4.41±0.41^{a}	5.16±0.40^{a}	5.23±0.40^{a}
H^{+} + A^{3+} (cmol$_{c}$ kg^{-1})	0-15	0.20±0.09^{a}	0.69±0.1^{a}	0.29±0.09^{a}	0.16±0.05^{a}
	15-30	0.27±0.10^{b}	0.74±0.08^{b}	0.38±0.10^{b}	0.19±0.05^{b}
	30-45	0.35±0.13^{c}	0.79±0.31^{c}	0.46±0.13^{c}	0.22±0.06^{c}
K^{+} (cmol$_{c}$ kg^{-1})	0-15	0.29±0.07^{a}	0.06±0.02^{b}	0.07±0.02^{b}	0.08±0.02^{b}
	15-30	0.30±0.06^{a}	0.04±0.02^{a}	0.05±0.02^{a}	0.06±0.02^{a}
	30-45	0.30±0.04^{a}	0.04±0.02^{a}	0.049±0.02^{a}	0.06±0.02^{a}
Mg^{2+} (cmol$_{c}$ kg^{-1})	0-15	1.66±1.13^{a}	0.61±0.33^{b}	0.70±0.34^{b}	0.95±0.37^{b}
	15-30	1.47±0.97^{a}	0.43±0.16^{a}	0.52±0.16^{a}	0.80±0.24^{a}
	30-45	1.37±0.32^{a}	0.43±0.21^{a}	0.53±0.21^{a}	0.80±0.24^{a}
Ca^{2+} (cmol$_{c}$ kg^{-1})	0-15	9.83±1.58^{b}	1.24±0.46^{a}	1.10±0.48^{a}	1.92±0.47^{a}
	15-30	9.56±1.31^{a}b	1.27±0.64^{a}	1.15±0.67^{a}	1.92±0.64^{a}
	30-45	9.23±1.04^{a}	1.23±0.68^{a}	1.09±0.71^{a}	1.85±0.69^{a}

AP= available phosphorus, ^{OC}=organic carbon, N=total nitrogen, exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and exchangeable acidity (H^{+} + Al^{3+}). Means that do not share a letter are significantly different ($p \leq 0.05$).

Table 3: Mean horizontal distribution of soil physical properties among land use types

Land use Types	Bulk density (g cm^{-3})	Moisture content	Sand	Silt	Clay
		%			
Arable	1.09+0.20^{a}	15.26+7.35^{b}	60.67+3.54^{a}	13.56+4.152^{c}	25.77+3.60^{d}
Fallow	1.08+0.14^{a}	16.29+7.43^{ab}	41.34+3.58^{b}	20.06+3.10^{b}	38.60+2.47^{c}
Pasture	1.16+0.10^{a}	14.89+2.39^{b}	43.14+2.26^{b}	15.43+2.645^{c}	42.64+2.75^{b}
Plantation	0.96+0.16^{b}	18.4+3.18^{a}	31.81+4.71^{c}	23.08+4.91^{a}	45.44+4.83^{a}

Means that do not share a letter are significantly different.

Table 4:Mean horizontal Distribution of soil chemical properties among land use types

Land Use Types	OC	N	AP (Mg kg^{-1})	pH (2:5)	K^{+}	H^{+} + Al^{3+}	Ca^{2+}	Mg^{2+}
	%				cmol$_{c}$ kg^{-1}			
Arable	1.99+0.98^{b}	0.19+0.07^{a}	9.56+1.36^{a}	5.33+0.15^{a}	0.30+0.10^{a}	0.28+0.09^{c}	9.54+3.52^{a}	1.50+1.67^{a}
Fallow	1.14+0.25^{d}	0.12+0.03^{b}	2.81+0.97^{c}	4.48+0.29^{b}	0.05+0.02^{b}	0.74+0.26^{a}	1.25+0.286^{b}	0.50+0.26^{b}
Pasture	1.55+0.41^{c}	0.12+0.03^{b}	4.71+2.37^{b}	5.23+0.29^{a}	0.06+0.017^{b}	0.38+0.13^{b}	1.16+0.63^{b}	0.52+0.25^{b}
Plantation	2.59+0.85^{a}	0.17+0.20^{ab}	2.90+1.22^{c}	5.27+0.30^{a}	0.06+0.03^{b}	0.19+.04^{d}	1.88+0.31^{b}	0.84+0.51^{b}

AP= available phosphorus, OC= organic carbon, N= total nitrogen, Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}), Exchangeable acidity (H^{+} + Al^{3+}). Means that do not share a letter are significantly different.

Bulk density

The vertical distribution of bulk density of soil across the identified land use types is presented in Table 1. The bulk density declined with depth followed the order 0-15 cm > 30-45 cm > 15-30 cm for all land use types except for fallow which followed the order 15-30 cm > 30-45 cm > 0-15 cm. The differences in bulk densities among the depths on all the land use types were significant ($p < 0.05$).

The horizontal distribution of bulk density among land use types is presented in Table 3. A significant ($p < 0.001$) variation was only observed between plantation and the non-plantation fields where bulk density in the plantation decreased by 21, 14 and 13 % relative to pasture, arable, and fallow respectively (Table 3). However, the bulk densities in pasture, arable and fallow were similar to one another at 15 cm layer (Table 3). The plantation consistently recorded the least bulk density both vertically (Table 1) and horizontally (Table 3).

Moisture content

The mean values and their associated standard deviations are presented in Table 1 and 3. In Table 1, moisture content significantly decreased with depth under each land use type. Apart from the fallow parcel, the observed decrease in moisture content from one depth to another in the other fields was insignificant. In Table 1, the distribution of moisture content in each land use type at various depths showed similar patterns.

Horizontally, the distribution of moisture content was not significant ($F = 2.38$; $p = 0.07$) within the entire field. Moisture content recorded at the plantation was significantly higher compared to arable, and pasture by 17.07 %

and 19.08 % respectively but slightly higher than fallow by 11.47 % (Table 3). Similarly, the moisture content distribution followed the order pasture ≤ arable ≤ fallow ≤ plantation (Table 3). This means that the order of moisture content at surface layer (0-15 cm depth) decreased as one moved away from the plantation towards the pastures. In general, vertical distribution of measured moisture content in each land use type was variably insignificant though moisture content generally appeared to be dominant at uppermost depth (Table 1). Horizontal-wise distribution of moisture content also indicated that plantation field significantly contained more moisture than arable, pasture and fallow.

Soil texture

The particle size distribution of each stratum is displayed in Table 1 and 3. The soil texture of arable, fallow, pasture and plantation were identified as sandy clay loam, clay loam, clay and clay respectively.

The results revealed that the sand (%) fraction decreased steadily from near surface to the bottom in each land use type except for pasture (Table 1). Though, there were changes in the sand fraction from one depth to another in each land use type, the changes were not significant. In Table 3, the differences in sand fractions were significant (F = 329.90; $p < 0.001$) among the land use types. The sand content was significantly higher in arable than fallow, pasture and plantation by 31.86, 28.89 and 47.57 % respectively. However, the differences between pasture and fallow recorded were not significant but were significantly ($p < 0.001$) higher than that of the plantation.

The sand fraction showed a very weak inverse correlation with SOC for 15-30 cm and 30-0.45 cm layers with the exception of 0-15 cm depth (Table 5). From table 3, generally there was non-significant relationship between sand fraction and organic carbon content in soil across these three depths in each land use type. Similarly, SOC significantly inversely associated with sand fractions in plantation and pasture but no significant association was established in the arable and fallow (Table 6).

The 15-30 cm depth recorded the highest silt fraction whiles the least was observed 0-15 cm depth in arable field (Table 1). The trend of silt fraction distribution in the other land use types followed similar pattern as in the arable field. Generally, the silt fraction for all the land use types were significantly ($p < 0.005$) higher at 15-30 cm depth relative to the other depths.

The silt fraction recorded in plantation was greater than arable, pasture and fallow by 41.25, 33.15 and 13.08 % respectively. The mean silt fraction in pasture and arable were similar but significantly lower than the fallow. The silt fraction distribution showed a pattern; arable ≤ pasture < fallow < plantation. From Table 5, the SOC had a significant positive weak correlation with silt (%) content at 15-30 cm depth and 30-45 cm depth whiles no significant correlation occurred at surface depth. Conversely, there was no significant correlation between silt fraction and SOC among the land use types (Table 6).

The clay fraction distribution in each stratum is presented in Table 1. The mean clay contents recorded for 15-30 cm depths in the fallow and pasture fields significantly ($p < 0.001$) differed from 0-15 cm and 30-45 cm. The trend of clay fraction with respect to depth did not follow any specific pattern on all the fields (Table 1). Table 3 also showed significant ($p < 0.05$) disparity in the horizontal distribution pattern of clay fraction among the land use types. The mean clay fraction was significantly higher in the plantation field than pasture, fallow and arable fields by 6.16, 15.05 and 43.29 % respectively. Clay fraction in pasture was considerably higher relative to fallow and arable by 9.47 and 39.56 % respectively. Furthermore, clay (%) in the arable was significantly lower by 33.24 and 39.87 % as compared to fallow and pasture respectively.

Table 5: Pairwise Pearson's Correlations showing the vertical distribution between SOC and soil properties

F pr.= F probability ($p \leq 0.05$), AP= available phosphorus, Db=bulk density,

Soil	**0-15 cm**		**15-30 cm**		**30-45 cm**	
Properties	**Correlation**	**F-pr.**	**Correlation**	**F-pr**	**Correlation**	**F-pr**
N (%)	0.304	<0.001	0.161	0.002	0.227	<0.001
Db (g cm^{-3})	-0.175	<0.001	-0.369	<0.001	-0.277	<0.001
MC (%)	0.112	0.034	0.24	<0.001	0.238	<0.001
AP (Mg kg^{-1})	0.151	0.004	0.175	<0.001	0.167	0.002
pH (2:5)	0.573	<0.001	0.435	<0.001	0.253	<0.001
Sand (%)	0.015	0.779	-0.062	0.245	-0.035	0.516
Silt (%)	0.098	0.064	0.246	<0.001	0.210	<0.001
Clay (%)	-0.072	0.177	-0.066	0.216	-0.070	0.185
Ca^{2+} (cmol$_c$ kg^{-1})	0.347	<0.001	0.292	<0.001	0.306	<0.001
Mg^{2+} (cmol$_c$ kg^{-1})	0.232	<0.001	0.290	<0.001	0.372	<0.001
K^+ (cmol$_c$ kg^{-1})	0.339	<0.001	0.316	<0.001	0.314	<0.001
$H^+ + Al^{3+}$ (cmolc kg-1)	-0.624	<0.001	-0.441	<0.001	-0.494	<0.001

MC= moisture content, N=total nitrogen, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, H^+Al^{3+}), exchangeable acidity (H^+Al^{3+}).

The clay fraction did not correlate with SOC across the three soil depths (Table 5) and all the land use types (Table 6)

Soil Chemical properties

pH

The mean pH of soils of the land use types are presented in Table 2. The pH decreased with increasing depth in each land use. pH decreased significantly (*p* = 0.001) between 0-15 cm and 30-45 cm depths in each field. However, for 0-15 cm and 15-30 cm depths, pH of soils was similar (Table 2). The distribution pattern of pH followed a pattern of 30-45 cm < 15-30 cm <0-15 cm depth (Table 2).

Spatially, the pH in each land use type varied significantly (F = 70.37; *p* = 0.001) from the other. It was noticed that pH of fallow was significantly (*p* = 0.007) lower than the arable, pasture and plantation fields by 18.97, 16.74 and 17.63 % respectively (Table 4). However, there was no significant differences in pH among arable, pasture and the plantation (Table 4).

Vertically, there was a significant positive correlation between pH and SOC (Table 5). A significant moderate positive correlation between pH and SOC at 0-15 cm and 15-30 cm depths whiles at 30-45 cm depth, a significant weak positive correlation was observed (Table 5). Spatially, no significant correlation was established between pH and SOC in arable, pasture and plantation lands. However, SOC and pH showed a very weak positive relationship in the fallow (Table 6).

Available phosphorus

In Table 2, the available phosphorus (AP) concentration at surface (0-15 cm) depth differed significantly ($p < 0.05$) from the other depths in each stratum. Generally, AP was concentrated on the near surface layers and declined progressively with depth; resulting in a pattern of 30-45 cm ≤ 15-30 cm < 0-15 cm among the four types of land uses. The available P in fallow at the top declined by 21.35 and 29.19 % at 15-30 cm and 30-45 cm depths respectively.

Table 6: Pearson's Correlation Coefficient showing the horizontal distribution between SOC and other soil properties distribution under land use types

Land use types	**Arable**		**Fallow**		Pasture		**Plantation**	
Soil Properties	**Correlation**	**F pr.**	**Correlation**	**F pr.**	**Correlation**	**F pr.**	**Correlation**	**F pr.**
N *(%)*	0.108	0.079	-0.11	0.072	0.057	0.353	-0.335	<0.001
Db *(g cm^{-3})*	-0.128	0.037	-0.003	0.961	0.118	0.054	0.107	0.082
MC *(%)*	0.138	0.024	0.099	0.106	-0.022	0.715	-0.039	0.526
AP (Mg kg^{-1})	0.257	<0.001	-0.018	0.765	0.253	<0.001	0.201	0.001
pH (2:5)	0.093	0.129	0.191	0.002	0.097	0.116	0.086	0.162
Sand (%)	0.029	0.634	0.084	0.171	-0.002	0.98	-0.045	0.466
Silt (%)	-0.083	0.174	-0.027	0.661	0.098	0.111	0.051	0.404
Clay (%)	0.058	0.349	-0.042	0.499	-0.084	0.17	-0.009	0.883
Ca^{2+} (cmolc kg^{-1})	0.103	0.093	0.197	0.001	-0.646	<0.001	-0.558	<0.001
Mg^{2+}(cmolc kg^{-1})	0.134	0.029	-0.015	0.811	-0.308	<0.001	-0.262	<0.001
K^+ (cmolc kg^{-1})	0.009	0.883	0.061	0.324	0.245	<0.001	0.165	0.007
$H^+ + Al^{3+}$ (cmolc kg^{-1})	0.141	0.021	-0.212	<0.001	0.142	0.02	-0.1	0.104

F pr.= F probability ($p \leq 0.05$), AP = available phosphorus, Db=bulk density, MC = moisture content, N = total nitrogen, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+) and exchangeable acidity ($H^+ + Al^{3+}$).

Generally, no significant difference in mean AP at 15-30 cm and 30-45 cm depths were detected in each land use type. There was an inverse relationship between mean values of AP and soil depth.

The horizontal distribution of AP among the various types of land use is presented in Table 4. The concentration of AP among these different land use types were significantly (F = 121.39; $p < 0.001$) different. Available phosphorus concentration in the arable was greater than that in fallow, pasture and plantation by 70.61, 502.73 and 69.67 % respectively. Among the non-arable land uses, pasture recorded a significant higher concentration of AP by 40.01 and 38.43 % than that of fallow and plantation respectively. However, no significant variation in AP concentration between fallow and plantation was observed. The magnitude of AP concentration among land use types was in order of arable > pasture > plantation ≥ fallow.

Available phosphorus had a significant very weak positive correlation with SOC (Table 5). Apart from fallow land, very weak positive significant association between AP and SOC was observed (Table 6).

Exchangeable cations

Exchangeable calcium (Ca^{2+})

Table 2 presented vertical distribution of Ca^{2+} comprising means and associated standard deviations of the studied land uses. Of these land uses, it was only in the arable field where Ca^{2+} recorded at 0 to 15 cm depth varied significantly ($p < 0.011$) from 30-45 cm depth (Table 2). No significant variation in Ca^{2+} at soil depths was observed under fallow, pasture and plantation. Presented in Table 4 is the distribution of Ca^{2+} among land use types. Exchangeable calcium varied significantly (F = 154.06; $p < 0.001$) among these land use types. Interestingly, a pronounced variation in Ca^{2+} between arable and the non-arable fields was detected. Moreover, arable recorded a significant higher exchangeable calcium by 86.90, 87.84, and 80.29 % than that of fallow, pasture and plantation, respectively. However, among the non-arable land use types, no significant difference in Ca^{2+} concentration was observed. Generally, Ca^{2+} level followed the order arable > plantation ≥ fallow ≥ pasture.

Furthermore, Table 5 showed the correlation between Ca^{2+} and SOC distribution in each land use type. Exchangeable calcium exhibited a significant weak positive relationship with SOC. In Table 6, exchangeable calcium (Ca^{2+}) moderately negatively correlated with SOC in pasture and plantation fields. However, a statistical very weak positive relationship was found between SOC and Ca^{2+} in the fallow but no significant correlation was recorded in the arable.

Exchangeable magnesium

Table 2 displayed the distribution of exchangeable magnesium (Mg^{2+}) among land use types. For arable, the diminution in Mg^{2+} with increasing depth was not significant. The mean Mg^{2+} in arable land across soil depths were insignificant. For fallow, pasture and plantation fields, Mg^{2+} equally diminished with depths. Among these land use types, Mg^{2+} at 0-15 cm varied significantly from the other depths. However, no statistical variation was observed between 15-30 cm and 30-45 cm depths.

Concentration of exchangeable magnesium (Mg^{2+}) among the four land use types significantly (F = 8.25; $p < 0.001$) varied from one another (Table 4). However, a significant variation was only observed between arable and the non-arable land use types. In addition, Mg^{2+} level in fallow, pasture and plantation significantly declined by 66.67, 65.33 and 46.67 % respectively relative to the arable. No statistical differences in Mg^{2+} were observed among pasture, fallow and plantation.

A significant weak positive correlation was observed between exchangeable magnesium and SOC content (Table 5). This means that an increase in SOC may not result in a significant increase in Mg^{2+} and vice versa among the various land use types. The SOC showed a very weak positive correlation with Mg^{2+} in the arable but an insignificant inverse correlation in the fallow. However, SOC statistically weakly inversely correlated with Mg^{2+} in pasture and plantation fields (Table 6). This suggests that increasing SOC in plantation and pasture parcels may potentially decrease Mg^{2+} level slightly and vice versa.

Exchangeable potassium (K^+)

Exchangeable potassium (K^+) concentration in each land use type differed significantly ($p < 0.001$) apart from the arable field (Table 2). For arable, K^+ was uniformly distributed across the three depths, hence, no significant difference was observed. However, K^+ was highly concentrated in topmost layer (0-15 cm) and declined minimally between 15-30 cm and 30-45 cm layers for fallow, pasture, and plantation. The order of K^+ distribution in pasture, fallow and plantation was 0-15 cm > 15-30 cm = 30-45 cm depths. Generally, exchangeable potassium at 0-15 cm depths were statistically greater compared to that of 15-30 cm and 30-45 cm depths. However, no statistical differences were observed between 15-30 cm and 30-45 cm depths under pasture, fallow, and plantation. Presented in Table 4 showed K^+ in each land use type. From Table 4, a significant ($F = 145.5$; $p < 0.001$) difference in K^+ content was observed between the non-arable and arable fields. Furthermore, a statistical decrease of 83.33 % in K^+ level was observed in the fallow whereas a decrease of 80 % in K^+ was recorded in both pasture and plantation relative to arable (Table 4). The mean concentration of K^+ were similar amongst the non-arable sites.

Table 5 presented the correlations coefficient between SOC and K^+ at various soil depths. It was noted that an increase in SOC content will correspondingly increase potassium ($p < 0.001$). This means that when SOC is increased, K^+ level may increase. The SOC had a weak positive association with K^+ in both plantation and pasture. Conversely, no association was established between SOC and K^+ (Table 6).

Exchangeable acidity ($H^+ + Al^{3+}$)

Table 2 showed exchangeable acidity determined in each land use type. Exchangeable acidity generally increased statistically ($p < 0.001$) with depth in each land use. In Table 2, the recorded $H^+ + Al^{3+}$ was in the order 0-15 cm < 15-30 cm < 30-45 cm depths in each land use type. Exchangeable acidity distribution trend suggests that the property changed with depth among the land use types.

The mean $H^+ + Al^{3+}$ among land use types significantly (F= 3.17; p = 0.027) varied from one another (Table 4). Among these land use types, a significant reduction in $H^+ + Al^{3+}$ by 62.16, 48.65 and 74.32 % in the arable, pasture and plantation, respectively compared to the fallow was observed. Moreover, $H^+ + Al^{3+}$ in the plantation significantly declined by 47.37 and 50 % compared to arable and pasture respectively. The mean $H^+ + Al^{3+}$ in Arable was significantly lower than that of the pasture by 26.32 %.

Exchangeable acidity showed a statistical ($p < 0.001$) negative correlation with SOC across soil depths (Table 5). This implies that increasing SOC will significantly reduce $H^+ + Al^{3+}$ toxicity in soils. The SOC in the arable and pasture directly correlated with exchangeable acidity. However, $H^+ + Al^{3+}$ had a significant but weak inverse correlation with SOC in the fallow (Table 6).

Total nitrogen

The total nitrogen (%) among land use types showed mean values and their corresponding standard deviations (Table 2). The mean total N was not statistically influenced by soil depths in each land types. Table 4 indicated the total nitrogen level of each land use type. Total N varied significantly (F = 3.17; p = 0.027) among these land use types (Table 4). Arable land recorded a significant higher total N (%) by 36.84 % relative to both fallow and the pasture. However, the 10.53 % decrease in plantation relative to the arable was not significant. Furthermore, the differences in mean total nitrogen (%) for fallow, pasture and plantation fields were similar.

In Table 5, SOC showed significant positive weak correlation with total nitrogen at soil depths. A weak positive correlation was observed at 0-15 cm 15-30 cm and 30-45 cm depths. This implies that an increase in total nitrogen in soil depth could result in an increase in SOC and vice versa. Soil organic carbon significantly negatively weakly correlated with total nitrogen only in the plantation (Table 6). However, no significant correlation was observed between SOC and total nitrogen in arable, pasture and fallow lands (Table 4). This means that an increase in SOC may not necessarily change the quantity of total nitrogen in these land use types.

Soil organic carbon

The distribution of soil organic carbon (SOC) is presented in Table 2 where land use types clearly explained their significant ($P < 0.001$) influence on SOC variability among soil depths. The concentration of SOC showed significant difference in a decreasing trend with depth. The mean distribution of SOC at 0-15 cm was significantly higher but lower at 30-45 cm depth compared to 15-30 cm depth in all the land use types. For instance, in the arable, SOC was significantly higher at 0-15 cm than 15-30 cm and 30-45 cm depths by 10.31 and 26.91 % whiles at 30-45 cm depth, SOC decreased significantly by 18.5 % compared to 15-30 cm depth. Soil organic carbon levels in the arable followed the pattern of 0-15 cm > 15-30 cm > 30-45 cm. Similar trends were observed in SOC distributions in fallow, pasture and plantation (Table 2). In the plantation, SOC was highly concentrated at 0-15 cm depth compared to 15-30 cm and 30-45 cm depths by 9.73 and 23 % respectively. At 15-30 cm depth, the mean SOC was significantly higher than 30-45 cm depth by 14.66 % in the plantation. The SOC recorded for 30-45 cm depth was significantly lower by 38.10 and 27.78 % than 0-15 cm and 15-30 cm depths respectively in the pasture. For fallow land similar trend was observed where 0-15 cm depth recorded a significant higher SOC compared to 15-30 cm and 30-45 cm depths by 32.06 and 27.64 % respectively. The SOC gain among land use types, particularly in plantation and arable at lower depth (30-45 cm) was statistically higher compared to the other depths in fallow and pasture lands. This explained the role subsoils play in SOC conservation. In Table 4, the distribution of SOC among land use types differed significantly ($F = 25.02$; $p < 0.001$) from one another. Plantation recorded a significant higher SOC relative to arable, fallow and pasture by 23.17, 55.98

and 40.15 % respectively. A significant decrease in SOC by 22.11 and 42.71 % in pasture and fallow respectively compared to that of arable was also observed. Additionally, fallow recorded lower SOC compared to pasture by 26.45 %.

From Table 5, close to 66 % of the selected soil properties studied positively correlated with SOC at soil depth. Soil organic carbon also had a statistical inverse association with bulk density and exchangeable acidity with the exception of sand and clay fractions which were not significant at various soil depths (Table 5). Also, SOC significantly positively correlated with moisture content in the order 0-15 cm, < 15-30 cm = 30-45 cm depths (Table 5). For land use types, SOC correlated positively with just about 25 % of the soil of properties (Table 6). For instance, in the arable, SOC significantly positively correlated with only moisture content, AP, Mg^{2+} and $H^+ + Al^{3+}$ but negatively with bulk density (Table 6). Under fallow field, SOC statistically positively correlated with pH, and Ca^{2+} but negatively with $H^+ + Al^{3+}$. The SOC also had a positive association with AP, K^+ and $H^+ + Al^{3+}$ but inversely related with Ca^{2+} and Mg^{2+} under pasture. Under the plantation, SOC exhibited a significant positive relationship with AP and K^+ but negatively associated with total nitrogen, Ca^{2+} and Mg^{2+} (Table 6).

In a nutshell, about 54, 77, 69 and 62 % of these properties in arable, fallow, pasture and plantation respectively varied significantly from depth to depth. And the spatial distribution of each soil property was significantly different with plantation recording the highest SOC.

CHAPTER FIVE

DISCUSSION

Soil Physical Properties

Bulk density

The dissimilarity in bulk density could be attributed to non-uniformity of management practices, texture of soil and the content of organic carbon (Wolf & Snyder, 2003). The results indicated that SOC was higher for lower soil bulk density (Table 3) which buttressed studies conducted by Chaudhari *et al*. (2013) and Owusu Prempeh (2015). Constant replenishment of carbon-rich litters from oil palm and coconut trees may have largely explained the observed lowest Db values obtained in plantation (Khanal, Sharma, & Upadhyaya, 2010). The relatively higher soil organic carbon content encourages aggregation (Toru & Kibret, 2019), increases the volume of soil without affecting its weight (Amanuel, Yimer & Karltun, 2018) and holds high proportion of pore space to solids, hence, lowered the Db (Bore & Bedadi, 2015). This implies that increasing clay fraction, OC and moisture content with less soil disturbance results in lowering bulk density of soil (Amanuel *et al.*,2018). This finding corroborated with Askin and Ozdemir (2003) who found that a little increase in SOC and clay content could equally decrease Db.

The findings were in line with Fantaw and Abdu (2011), Takele *et al.* (2015) and Nigussie (2017) who also reported least bulk density in plantation sites as compared to pasture and arable lands in western and central highlands of Ethiopia. Takele *et al*. (2015) ascribed the rate of disturbance and organic carbon as causes of low and high bulk densities of soils under permanent plant cover and cultivated lands which are not under permanent cover respectively.

From Table 1, the high mean bulk density for pasture in the topsoil (0-15 cm depth) was similar to the findings of Panday *et al.* (2018) who attributed high bulk density in grassland to compaction effect resulting from prolonged animal trafficking and trampling during grazing on this bare pasture. High bulk density is directly related to high compaction but inversely associated with porosity of soil (Nanganoa *et al.*, 2019). Higher bulk density and lower SOC values in arable compared to plantation field could probably be attributed to variation in texture and soil management practices (e.g level of disturbances) (Table 3). The finding was similar to the report of Hajabbasi, Jalalian, and Karimzadeh (1997) who observed that replacing tree cropping for arable production increased bulk density but decreased organic carbon between 0 to 30 cm depth of soil for over two decades in central Zagros in Iran. The higher bulk density of arable land was also likely to be due to continued tillage practices that interrupts the structure of the soil, causing compaction of surface soil layer (Amanuel *et al*., 2018). Tillage in turn reduces the organic C in the soil, thereby exposing OC to microorganisms as observed by He, Kuhn, Zhang, Zhang and Li (2009). The observed higher bulk densities on surface soils arable and pasture could have been influenced by the level of disturbance, movement of heavy machinery coupled with texture and moisture content effect.

Generally, the bulk density inversely correlated with SOC, MC, and clay (Appendix A4-A6). This confirmed the converse association between organic carbon and bulk density in the studied land use types as observed by Panday, Ojha, Chalise, Das and Twanabasu, (2019), Chaudhari, Ahire, Vidya, Chkravarty and Maity (2013) and Nascente, Yuncong and Carlos (2015).

Moisture content

In Table 3, the highest MC recorded in plantation could be attributed to high clay content, OC, soil management practices, vegetative cover (Murphy, 2015) and low bulk density. The versatile nature of organic C increased soil water holding capacity due to the increased number of macro pores in the top and sub soil layers. Zero tillage practices, litter falls serving as mulch and less movement of heavy machinery in the plantation encourage high water retention and infiltration, accounting for the higher moisture content in the plantation as ccompare to the pasture. Micro-pore components in the porosity of soils have a superior role in water retention by soil (Kandagor, 2015). The prevalence of relatively lower amount of surface exposure to direct sun rays due to permanent plant cover in the plantation probably also accounted for the higher moisture (Amanuel *et al.*, 2018).

On the other hand, the least MC recorded in the pasture field (Table 3) may be due to soil compaction resulted from trampling of animals. Heavy grazing brings about trampling by animals and this probably resulted in low infiltration of water (Zhao, 2007). The decrease in MC at 0-15 cm, 15-30 cm and 30-45 cm by 17.74, 18.38 and 18.86 % respectively in the pasture relative to plantation field could be attributed to the observed high bulk density in the farm.

Soil texture

Generally, the textural class of the field could be described as clay loam in nature, (Table 1 and 3). This may be due to the fact that these soils were formed from similar parent material (Bore & Bedadi, 2015). Further analysis of the textural classes of each land use type revealed that, arable field was sandy clay loam, clay loam for fallow field, clay for both pasture and plantation land across the three soil depths (Table 1). Variation in clay and sand fractions across the field generally could be due to soil management practices and erosion. Lack of proper soil management practice including water conservation measures, the arable field suffered erosion of clay fractions via either water or wind uplands to low lying areas (Bore & Bedadi, 2015).

The variations in textural classes in this study was akin to Agoume and Birang (2009) who found that physical properties including soil textural classes reflected current land use systems and management practices. Fraction of sand decreased as soil depth increased, whereas clay decreased with it. From Appendix A3-A9, sand fraction showed an inverse relationship with silt and clay fractions moving from arable, fallow, pasture to plantation and from top downwards across the field. The clay loamy nature of topmost (0-15 cm depth) soil coupled with its ability to sequester atmospheric CO_2 and point of organic material deposit within and aboveground also accounted for the higher SOC contents at the various land use types. The soil texture for pasture was averagely, clay with high bulk density (1.11-1.20 g cm^{-3}) within the generic horizons (0-30 cm depth) (Table 1). The presence of more sand (%) in arable field than the other fields may be attributed to excessive tilling and subsequent erosion. Constant disturbance with little or no measures to conserve or manage soil and water exposed the field to erosion (Bore & Bedadi, 2015). Similarly, Chimdi, Gebrekidan, Kibret, and Tadesse (2012) reported that some physical properties of soil reflect current land use and management practices, hence, accounted for the variation of these properties under the current land use types in the farm.

Increased sand content by 47.67, 48.12 and 47.76 % at 0-15 cm, 15-30 cm and 30-45 cm soil depths respectively in the arable relative to plantation is an indication of selective removal and erosion of finer particles (silt and clay). Again, intense tillage activities in arable field accelerates weathering of soil particles, hence, in times of run off, the finer particles easily suspend, eroded and redeposited at the plantation field which is located at gently and low-lying area. With respect to the pasture field containing the second highest sand (%), the continuous stamping of animals on the soils in the field could have probably led to soil compaction, hence, low water infiltration capacity and any little rainfall results in run off and subsequent erosion of fine particles to low-lying parts of the field. During grazing, the stamping could result in detachment of soil particles and the presence of wind and/ or rain could erode the finer particles of the soil. Finer particles eroded from other land use types subsequently accumulated in the plantation field of the study area where there was a permanent plant cover to impede the direct effect of rain and wind on surface finer particles, hence, resulted in increasing the clay fraction by 43.56, 44.21. and 43.04 % relative to the arable at 0-15 cm, 15-30 cm and 30-45 cm respectively (Table 1). The dominance of clay content in plantation field attested to the work of Ellerbrock and Gerke (2013) and Yimer, Ledin, and Abdelkadir (2007) where they pointed out that clay particles are easily eroded and redeposited at the topographic depressions (lower lying site).

Soil Chemical Properties

pH

Soil pH is very crucial as it influences the availability of the various ions of fertilizer nutrients. Soil pH affects activities of soil microorganisms. In highly acidic soil, there is low organic carbon decomposition due to declined bacteria population, hence, their inability to act on accumulated organic materials and bound nutrients, particularly nitrogen.

The findings revealed that with the exception of soil pH under fallow field which is very strongly acidic at 0-15 cm and 15-30 cm depths, the other fields were predominantly strongly acidic across the three depths (Table 2). The finding corroborated with the assertion that most soils in the tropics are acidic (Nanganoa *et al*., 2019). The pH of plantation field where oil palm and coconuts are grown conformed to Nanganoa *et al.*, (2019) report where they found that pH within 4.3–6.5 favours the cultivation of Oil Palms (Table 4). Acidic soils (pH < 5.5) are widespread, and cover 30 and 60 % of the worlds and tropic's total land areas respectively (Fujii, 2014).

Generally, the high pH levels in arable, pasture and plantation fields ranged between 5.27-5.33 (Table 4) are favourable for most plants growth as most nutrients become available in such pH ranges. The comparative higher pH values in the arable than fallow across all soil depths (Table 2) could be attributed to incorporation of manure and inorganic fertilizers containing NPK which could have enhanced high uptake of calcium and magnesium (Kandagor, 2015).

The relative higher pH values in soils of the field could be due to less usage of acid-forming fertilizers, such as di-ammonium phosphate $(NH_4)_2HPO_4)$, which produces strong acids when oxidized by soil microbes (Nega, & Heluf, 2013).

The significantly ($p < 0.001$) lowe pH recorded in the fallow (Table 4) could probably be attributed to deep percolation or runoff that brought about depletion of basic cations as equated to the pasture and plantation. The least mean pH value recorded in the fallow could be due to lack of soil management in the field to check its pH which was in line with Okae-Anti and Ogoe (2006) and Kpongor (2007), where they attributed low soil pH levels to the varying effects of soil management.

The relatively lower pH of the fallow field was probably due to the fact that the soil had not received animal manure application for long time, hence, probably having its bases leached, leading to increase in the levels of Al^+ ions. From Table 4, the dominance of $H^+ + Al^{3+}$ in fallow field might have limited the ability of the soil to absorb more Ca^{2+}, K^+ and Mg^{2+}, accounting for the low levels of these nutrients (Miller, 2016).

Exchangeable cations

Soil organic carbon contributes to exchangeable cations as its surfaces act as a point for cation exchange. As the exchangeable cations of SOC varies with pH, the effectiveness of SOC to contribute to exchangeable cations below pH 5.5 is often minimal (Murphy, 2015).

As per the ratings of FAO (2006) and Laekemariam, Kibret, and Shiferaw (2018), the exchangeable Ca^{2+}, K^+ and Mg^{2+} content were very low (< 4 $cmol_c$ kg^{-1}) in fallow, pasture and plantation at all soil depths except for Ca^{2+} in the arable (Table 2). The findings revealed that arable (cultivated) land had the relatively highest Ca^{2+}, K^+ and Mg^{2+} while the least was recorded in fallow field except for Ca^{2+}. This departed from the work of Bewket and Stroosnijder (2003) who reported higher Ca^{2+}, K^+ and Mg^{2+} values in fallow and least for arable field.

Low Ca^{2+}, and K^+ in the non-arable lands could be due to losses resulting from the soil acidity and dominance of exchangeable acidity ($H^+ + Al^{3+}$). As one moves from arable towards the pasture, the exchangeable Ca and K readily decrease with increasing $H^+ + Al^{3+}$, showing the declining dominance of exchangeable cations in the exchange complex of the soil colloids, hence, this result is in agreement with the findings of Jaiyeoba (2003). Similarly, low Ca^{2+}, Mg^{2+} and K^+ in fallow and pasture compared to arable land use types corroborated the findings of He *et al.* (1999) who reported the domination of soil by extractable Al^{3+}. Adsorption of the cations by higher content of clay in the non-arable resulted in relatively lower contents of Ca^{2+}, Mg^{2+} and K^+ ions in the soil.

Exchangeable calcium

Exchangeable calcium (Ca^{2+}) absorbed by roots largely depends on Phosphorus (P) availability. This implies that P serves as source of energy for the active absorption of mineral nutrients in the soil (Kandagor, 2015). This means that low P will result in inadequate supply of calcium, bringing about poor flowering and limited root development by plant. With the exception of arable land, exchangeable calcium values across soil depths (Table 2) and among all land use types (Table 4) generally significantly fell below the critical levels (1.6 to 10.0 $cmol_c\ kg^{-1}$) and so does not limit production. From Table 2 and 4, calcium is the dominant property among the exchangeable cations. The results of this findings reflected the widely accepted view that calcium is the dominant cation on the exchangeable cations in most soils. Calcium can readily desorb and replenish soil solution as needed for plant uptake. Like potassium, plant uptake is only one of the possible fates of calcium loss in soil solution.

The very low calcium recorded in fallow and pasture fields could be attributed to its mobility nature in the soil as it is susceptible to losses through leaching and precipitation as secondary minerals due to direct exposure to climatic factors (rainfall and temperature). The low Ca^{2+} in fallow and pasture compared to plantation might be due to high aluminium saturation caused by extremely acidic nature of the fields (Table 4).

Exchangeable magnesium

Exchangeable magnesium among land use types in the farm generally ranged between very low to medium relative to the critical value (0.8-4.0 $cmol_c$ / kg) per the rating of Kandagor (2015). The results revealed that arable had medium concentration of exchangeable magnesium whiles the other land use types were considered as having low concentrations (Table 3 and 4). The findings were likened to Landon (2014) and Laekemariam *et al*. (2018) ratings where exchangeable Mg concentration was classified as very low (< 0.5), low (0.5–1.5), medium (1.5–3.3), high (3.3–8.3) and very high (> 8.3 $cmol_c$ kg^{-1}). Based on these ratings the researcher concluded that exchangeable Mg levels in all the land use types were low. The low concentration of exchangeable Mg could be due to compromised absorption of Mg^{2+} resulting from critically deficient P levels across these non-arable fields studied. Also, the low Mg^{2+} recorded in these land use systems (Table 2 and 4) could be attributed to the acidic nature of the soils, continuous Mg removal and least SOC content concentration (Laekemariam *et al.*, 2018).

Magnesium is one of the key macronutrients in the nutrition of flowering plants; a major constituent of the chlorophyll molecule which facilitates in trapping photo radiation. Magnesium is a chlorophyll constituent, an important nutrient in the process of photosynthesis and induces roots budding. Its control the photo system of leaves of many crops including coffee (Kandagor, 2015), yet, it is deficient in the studied soil.

Exchangeable potassium

Potassium (K) supply in soil result from natural processes of weathering of primary minerals and dissociation from colloidal clay and humus. Climate (temperatures and rainfalls) also influence the availability of exchangeable potassium through decomposition of organic manure and subsequent release of potassium. When K is released but not taken up by plants, after it had been translocated out of the soil profile, will be leached. Conversely, absorption rate of calcium, other mineral nutrients and potassium from the soil is determined by the amount of phosphorus. The mean values and associated standard deviation of exchangeable potassium in Table 2 and 4 were within deficiency range. K^+ deficiency in soils is gaining global recognition as reported by many authors (Laekemariam *et al.*, 2018). The findings of the study are akin to several works. For instance, based on the rating of Kandagor (2015) and Panday *et al.* (2019), K^+ is low when it is between 0 - 0.40 $cmol_c\ kg^{-1}$ whiles very low (< 0.2 $cmol_c\ kg^{-1}$) to low (0.2– 0.5 $cmol_c\ kg^{-1}$) by Laekemariam's *et al.* (2018) rating.

According to Mbah (2008) and Uzoho and Ekeh (2014), availability and distribution of K^+ is influenced by the nature of the raw materials, weathering, type of land use, types of fertilizers used and the rate of their leaching, as well as the yield. Conversely, poor management practices such as continuous cultivation, non-addition of crop residues, erosion, improper fertilization among others probably exacerbated depletion of K^+ level (Laekemariam, Kibret, Mamo, Karltun & Gebrekidan, 2016).

The highest soil exchangeable potassium content observed in arable field though deficient, might be attributed to organic manure fertilization (Mikkelsen, 2007). Increased input of OC in arable compared to fallow land resulted in increased Ca^{2+}, Mg^{2+} and K^{+}, which potentially reduced the positively charged nutrients from leaching (Mbah, 2008). Also, repeated replenishment of crop residues containing accumulated K probably accounted for high mean K^{+} in the arable as Fageria, Baligar and Edwards (1990) noted that close to seventy per cent of total K accumulated in crops is stored in the residues.

However, the very low K^{+} levels observed in non-arable lands could be attributed to leaching especially in the plantation which contained the highest moisture content as compared to fallow and pasture lands (Table 2 and 4). Erosion and leaching of K^{+} resulted in depletion of basic cations in the non-arable fields (Akbas, Gunal, & Acir, 2017). Interestingly, the findings of this study with respect to plantation field which recorded the highest SOC conversely had low K^{+} confirming the findings of Panday *et al*. (2019) who observed that several places within their studied area with high OC had low K^{+} due to high erosion losses.

Very low levels of K^{+} in these non-arable lands could also be associated with disproportionate amounts of magnesium and /or calcium compared to potassium (Hillette *et al.*, 2015; Laekemariam, Kibret, Mamo, & Gebrekidan, 2016). Gross imbalance (induced deficiency) of magnesium and /or calcium could result in K^{+} deficiency even in soils containing optimum amount of exchangeable K as has been reported (Hillette *et al*., 2015; Laekemariam *et al*., 2016). The domination of $H^{+} + Al^{3+}$ on exchange complex over K^{+} in the non-arable fields have equally contributed to the very low to low K^{+} levels in these soils as it has the ability to reduce availability of K^+ and consequently result in K^+ deficiency (Laekemariam *et al*., 2016), confirming the observation made by Hoskins (1997) who established an unfavourable inverse relationship between a very high concentration of a cation in the soil and the availability and uptake of other cations by the plant. The widespread neglect of potassium fertilization in non-arable soils might have further depleted potassium reserves (Wassie, 2009, Hillete *et al*., 2015).

Generally, the finding of this study showed a statistical variation of exchangeable potassium among land use types and at varied soil depths, which suggest possibilities of risks associated with soil degradation (Kandagor, 2015).

Furthermore, the results of this study showed an order of $Ca^{2+} > Mg^{2+} > K^+$ for exchangeable cations availability (Table 2 and 4) which mimic the findings of Laekemariam *et al*. (2018) and Van Groenigen, Mutters, Horwath, and Van Kessel (2003) who equally reported soil exchangeable cations availability in similar order pattern.

Exchangeable acidity

The distribution of exchangeable acidity ($H^+ + Al^{3+}$) was very high in the fallow while plantation recorded the least (Table 2 and 4). Hinrich, Brian, and O'Connor (2001) reported that exchangeable acidity was a function of soil pH, comprised of weak organic acid ions and $Al(OH)^{2+}$ retained on the colloidal surfaces of soil.

The results of this study (Table 4) was similar to the findings of Bore and Bedadi (2015) where they attributed high soil exchangeable acidity to the occurrence of lower pH. The higher $H^+ + Al^{3+}$ in the fallow was probably due in part to plant uptake of Ca^{2+} or losses through leaching.

The decrease in exchangeable acidity in arable, pasture and plantation could be attributed to the increased pH and/or complexation of Al by solid-phase organic matter that favours a reduction in $H^+ + Al^{3+}$ concentrations in soil solution. The substantial lower $H^+ + Al^{3+}$ observed in plantation (Table 2 and 4) could be due to the higher concentration of SOC coupled with the high pH. This demonstrated how SOC can be used to remove Al from the soil solution (Miller, 2016).

This finding departed from the assertion that "it is a good rule of thumb that soils high in clay are also high in Al" as plantation field with highest clay content recorded the least Al^{3+} (Table 2 and 4). This justified the fact reported in literature that clay soils with higher exchangeable cations hold more bases (Ca, Mg, K, and Na) as well as acids (Al, H).

Total nitrogen

Land uses including field management practices influence total N levels in soils for plant uptake. The main source of nitrogen in soils at the study site might have been the decomposition and humification of organic matter, which was complemented with nitrogen fertilizers application. Total nitrogen across the four land use types under various depths averaged between 0.11- 0.20 % (Table 2 and 4) which could generally be described as very low to low (0.127 - 0.3) according to Kandagor (2015) rating. Based on the above classifications, all the land use types could be said to have low total nitrogen content and this could be attributed to long term management effects including nutrients removed by plants, disproportionate manures fertilization as well as high temperatures which favour decomposition and humification of organic carbo.

The results of this work departed from the findings of Yimer, Ledin, and Abdelkadir (2006) and Duguma, Hager and Sieghardt (2010) who found soil N contents to be significantly lower in the arable as against fallow and pasture as a result of hefty losses.

Although N was generally deficient across the field, comparing its level in arable to the non-arable uses, arable land could be considered as having the highest nitrogen content, probably, due to the cultivation of N-fixing species that sequestered more soil C than the other species owing to the extra nitrogen input. Higher content of total N in arable land could be attributed to different rates of decomposition and composition of SOC. Moreover, the observed higher total N in arable land might also be due to more mineralized organic carbon which makes nitrogen, sulphur and P available for crops. This does depend on past management of land, cropping systems, and pastures. Higher total N in arable could also be due to higher exchangeable cations that enhance retention of N-fertilizer including manure, and the cultivation of leguminous crops.

Swift mineralization ensuing agronomic activities, which disrupts aggregates of soil, and thereby exposing OC to microbes and aeration probably accounted for total N losses in the fallow and pasture. Low organic material input and leaching rates could have accounted for the low N levels in pasture and natural conditions. Minimal input of plant residues contributes to depletion of soil OC, hence, subsequent decline in N in the arable soils. Withdrawal of C inputs accounted for low N and OC in agricultural soils (Wang, Fu, Qiu & Chen, 2001). Furthermore, non-leguminous crop production system that could sequester more atmospheric nitrogen might explain the very low N among non-arable lands. The very low total N in these strata may also be lack of application of inorganic N-fertilisers to complement the naturally supplied N.

The distribution pattern of total nitrogen implies that N is not highly concentrated at 0-15 cm relative to 30-45 cm depths (Table 1). Probably, surface application and low leaching rate of N may have explained the higher nitrogen levels in topsoil which can be reached by many plants. However, the similarities in total nitrogen across soil depths amongst the four land use types especially in the arable indicate that some amount of total N leach in the soil. This explains the assertion that sandy soil risks N-leaching that could lead to underground water pollution due to high N concentration and subsequent eruption of eutrophication or methemoglobinemia (blue born baby syndrome among children). In addition, the lower N recorded at 0-0.15 m relative to 0.15-0.30 m depth of soils in pasture (Table 1) could probably be due to increased temperature that enhance microbial activity coupled with high emission of CO_2 to the atmosphere from the top layer (0-15 cm) resulted in 8.33 % decline of N (Chimdi, Gebrekidan, Kibret & Tadesse, 2012). Conversely, the presence of substantial amount of nitrogen content at deeper depths could be due to nitrate concentrations.

Nitrogen is a dynamic nutrient that constantly circulates between the atmosphere, organisms in soil, plant material, soil solution and SOM. The availability of nitrogen is important for increasing the SOC accumulation (Boddey *et al.*, 2010). Nitrogen-fixing legumes contribute significantly in increasing SOC stocks (Fornara & Tilman, 2008). The growth, quality and yield of crops is majorly determined by nitrogen compared to other nutrients. Nitrogen promotes leaf, root and stem growth of plants (Yuan *et al.*, 2012;

Sharma, Ram, Sharma, & Meena, 2013). Aside water, N is the most limiting factor to plant growth (Havlin *et al*., 2005).

In a nutshell, comparing total nitrogen level across the field to the rating of Kandagor (2015) all the land use types could be described as suffering from N deficiency despite N-fertilisation by farmers in the arable. The observed nitrogen level was significantly below the maximum value of 0.3 % of nitrogen that exists in cultivated soils as quoted by Rowell (Rowell, 1994).

Available phosphorus

The results revealed a significant concentration of available phosphorus (AP) in arable compared to the remaining land use types (Table 2 and 4). The significant higher AP in arable field (Table 4) was probably the continuous application of manure including farm yard manure for improving fertility of soil (Miheretu & Yimer, 2018) and inorganic fertilizers such as DAP that comprised 46 % P and 18 % N (Panday *et al*., 2018). The pH recorded in the arable field affirmed the assertion that an ideal pH that enhances availability of phosphorus ranges between 6.5 to 7.5 (Jensen, 2010). Due to tillage practices, soils in the arable field were exposed to higher temperatures, higher impact of rain drops and more aeration and these favourably influenced the rate of weathering, bringing about the release of more phosphorous into the soil. Ferralitic weathering process favours the development of pH dependent exchange capacity in the soil leading to high phosphate retention in arable field than the non-arable lands as observed in Gosai, Arunachalan and Dutta (2009) work. Phosphorous values on the research site were consistent with the report of Kpongor (Kpongor, 2007).

One the other hand, low P was found among the non-arable croplands especially in fallow and the plantation (Table 4). The low AP in the plantation could have been affected by the amount of clay content. High clay fraction implies an increase in its surface area where phosphate sorption can take place, hence, increasing P-sorption capacity of soil. The findings was in line with Kandagor (2015) work where he optimistically concluded that compromised Ca^{2+}, and K^{+}, including other mineral nutrients absorption contributed to acute P deficiency (Table 2 and 4).

However, low Ca^{2+}, Mg^{2+} and K^{+}, and dominance of clay content also accounted for the very low status of AP in the fallow and plantation. For instance, the acidic cations such as exchangeable Al, H, and oxides of Al and Fe might have fixed the soluble P in the soil solution hence, making P deficient in fallow. At low pH, soils contain higher amounts of aluminium in solution, which form very robust bonds with phosphate. Under such acidic situations, phosphorus become probable to react with aluminium and iron to form minerals, alongside strengite and variscite. The lower AP level in plantation among the four land use types mimicked previous works (Kharal *et al*., 2018). Moreover, because AP is highly pH-dependent, fallow land with the least pH correspondingly recorded the lowest AP level and this might be due to depletion of soil P by continuous plant (grass/ fodder) uptake and soil erosion. The reasons for the recorded deficient values of AP in fallow and plantation fields could be attributed to long-term removal of phosphorous by crops and non-systematic application of organic and inorganic manures. Substantial amount of phosphorous is taken up and incorporated into the system of root of crops (Howeler, 2002).

Soil organic carbon

The mean values obtained for both vertical (Table 2) and horizontal (Table 4) distribution of SOC were consistent with trends of SOC associated with land use change as reported by Guo and Gifford (2002) and Post and Kwon (2000). Ruan and Hardter (2001) assessing the fertility of soil for plantation in China, categorized it as follows: deficit fertility (< 1.5%), average fertility (1.5%–2.0 %) and fertility enrichment in a high-yield and high-quality (> 2.0 %). In view of this, plantation and arable fields could be considered as enriched with fertility and average fertility (Table 4), that could support the production of crops. However, the fallow and pasture fields, could be considered deficit in fertility (Ruan & Hardter, 2001). The findings revealed high concentration of SOC (> 2 %) content within the uppermost layer across the various land use types which decreased with increasing depth (Table 2). Saha (2008) who stated that in the tropics, organic matter makes up 3–5 per cent of the total soil mass and is located within 15 cm of the top soil buttressed the higher content of SOC at 0-15 cm in each land use type (Table 2).

The observed differences in SOC among land use types confirmed that modification of land use systems could result in changes in organic C in the soil globally (Deng, Zhu, Tang, & Shangguan, 2016; McNally *et al*., 2017). In Tables, 2 and 4, plantation field had the highest SOC whiles the least was recorded in fallow land. The findings corroborated with Guo and Gifford, (2002) who reported that SOC declined after conversion of pasture to plantation (-10 %), forest to plantation (-13 %), from forest to crop (-42 %) and pasture crop (-59 %) .

The highest SOC content in plantation land may be partly due to the continuous accumulation of un-decayed and partially decomposed plant residues in the surface of the soils. Another probable reason that could account for the highest SOC content in plantation field was the amount of clay content. Yu *et al*. (2019) observed that the stabilization of SOC was more strongly affected by the clay fraction of the soil via sorptive protection or by the formation of microaggregates with SOC in coniferous forests and chemical protection by the formation of organo-mineral complexes. Soil clay has significant effect on SOC stabilization, hence, the observed highest SOC in the plantation in the Table 4 (Percival, Parfitt & Scott, 2000; Gonçalves *et al.*, 2017). Plantation soil averaged about 45.44 % of clay while 23.08 % for silt fraction and 31.81% for sand fraction compared to the clay content in the other and use types (Table 4).

The high SOC content in the plantation at each soil depth (Table 2) could also be linked to frequent addition of plant litter left to rot on the field (Nanganoa *et al*., 2019), the presence of network of roots of oil palm and coconut trees, and modified microclimate, which retard decomposition rate of organic carbon. The higher SOC content in plantation relative to the other land use types can be due to the presence of woody perennials, well-built conservation structures and recurrence of partially decomposed organic carbon. Limited erosion due to minimal disturbance and protection of the soil from covering layer formed from the presence of the plants (oil palm and coconut trees) also accounted for its higher SOC concentration in the plantation field (Chalise, Kumar, Shriwastav & Lamichhane, 2018).

The findings agreed with Noordwijk *et al*. (2002) and Schmitt-Harsh, Castellanos, Evans and Randolph (2012) who reported higher SOC content under permanent tree cover than other land use types. Plantation crops have significant larger sequestration potential and are able to retain sequestered C for longer periods with smaller annual fluctuations (Kongsager, Napier & Mertz, 2013). Salehi, Ghorbanzadeh and Kahneh (2013) reported that the effects of trees on soil properties occur mostly due to increased organic carbon and the release of nutrients from it. In addition, microorganisms, animals, and roots contribute to increase in OC (Bizuhoraho, Kayiranga, Manirakiza & Mourad, 2018). Adsorption by soil minerals has also been proposed as an important mechanism to stabilize SOC, making it inaccessible to the microbial community, especially in acidic soils (Baldock & Skjemstad, 2000; Spielvogel *et al*., 2008).

The findings were in line with other studies in different areas that revealed low OC content of arable land compared to plantation could bewhich they attributed to increased rates of SOC mineralization, mainly due to tillage activities, decrease in total organic material inputs (garbage, crop residues and manure), increased soil temperatures due to soil surface exposure and increased wetting and drying cycles and losses due to soil erosion (Chroth, Vanlauwe & Lehmann, 2003; Kidanemariam, Gebrekidan, Mamo & Tesfaye, 2012). In addition to this, the well-drained soil conditions in arable probably increased the rate of SOC decomposition. Organic carbon content of the soil reflected the amount of organic material present in the soil and also serves as a source for macro nutrients such as nitrogen, phosphorus and sulphur in addition to some micro nutrients. Liguori, Gugliuzza, and Inglese (2009) also reported that many annual crops such as maize can fix more C than tree cropping systems in any given year, but their biomass usually decomposes rapidly, and the rate and return of sequestered C to the atmosphere are very fast.

The results of this work was similar to a study by Panday *et al*. (2018) who reported that, in parts of Nepal, intensive tillage has reduced the concentration of nutrients and OC in the soil, thus reducing soil fertility. Disposal of crop residues (Berry, 2011; Pan, Smith & Pan, 2009) and incineration of crop residues during land preparation (Awasthi, Singh, & Sitaula, 2005; Yeshanew, Zech, Guggenberger, & Tekalign, 2007) prior to sowing (Melero *et al.*, 2011) equally account for low SOC content in arable lands globally. The general view is that C accumulation is faster when land use change involves the transition from cultivated (degraded) land to permanent grazing land.

Comparing the SOC content in pasture to plantation (Table 4), it was probable that the lower carbon content recorded in pasture was due to the fact that some amount of SOC had been exported through intensive grazing. It was believed that the most commonly used over-grazing pressure in pasture field and the cutting and transportation system result in less organic substance entering the system (Riedo, Gyalistras, & Fuhrer, 2000; Nyssen *et al.*, 2008). Literature indicated that the impact of grazing on SOC ranged from very negative (Golluscio *et al.*, 2009) to very positive (Pei *et al.*, 2008).

The lower SOC content in fallow and pasture land compared to arable and plantation lands probably reflected the poor vegetative cover, erosion, and possible high concentration of labile SOC constituents such as polysaccharides and labile aromatic components, with low ^{13}C. Basically, the prevailing imbalance between biomass replenishment and organic carbon mineralization including anthropogenic factors like reduced biomass return and livestock grazing. This result is in agreement with those reported by Lemenih, Karltun, and Olsson (2005). Research revealed that most tropical soils were known to contain low levels of organic C, probably due to rapid decomposition rate resulting from warm climatic conditions coupled with limited cover. High temperatures favoured rapid rate of OC decomposition. Mineralization of the SOC pool might have subsequently led to carbon losses and therefore the general low levels of SOC in pasture and fallow fields. Different land management systems practices such as poor land management coupled with high decomposition and emission of abundant labile carbon into the atmosphere as well as low carbon sequestration potential might have resulted in low content of SOC in the fallow land. Land use and management that exert the least disturbance to soils enhance OC accumulation.

On the other hand, the study also found that SOC content was higher in pasture field as compared to fallow land (Table 2 and 4). This corroborated the findings of Conant *et al.* (2001) where they resolved that conversion of fallow land to grassland increased soil C for close to seventy per cent. Expansion in grazing land areas have increased the rate of carbon noticeably in the soil globally (FAO, 2015), hence, managing grazing in these lands appropriately could sequester substantial C from the atmosphere (Smith *et al*., 2008; Lal, 2009*)*. Pastures are characterised by grasses which produce high (more) roots that have high C accumulation rates as compared to fallow. Close to eighty per cent of plants in pastures are perennial and have well developed root systems that are used for storing C for new growth after grazing or in spring (Guo & Gifford, 2002). Tate, Scott, Ross, Parshotam and Claydon (2000) equally found that the carbon stored in fallow (native cover) was 13 per cent lower as compared to grassland for the entire profile studied in New Zealand. Guo and Gifford (2002) observed that establishing pasture on fallow (native cover) could averagely increase organic carbon in the soil by eight per cent even though dissimilarity exists, hence, justifying the close to 35.96 % increase in SOC content compared to the fallow (Table 4). Cerri *et al*. (2007) asserted that converting fallow to pasture may sequester a similar or even greater SOC content over the long term, despite an initial reduction.

Effective grass management systems might have accounted for the higher SOC content in pasture than that of fallow land since managing grass effectively is nearly equivalent potential to store organic C in the soil like a forest (Franzluebbers, Stuedemann, Schomberg & Wilkinson, 2000). Variations in soil C accumulation in these ecosystems could result from differences in plant carbon inputs (e.g., recalcitrant soil C stocks), soil aluminium and soil physical characteristics, rather than differences in mineral disintegration or texture of the soil. Reduced water (moisture content) and gaseous exchange in meadow soils due to the dense root net might have resulted in reduction in the rates of decomposition of SOC in the meadow ecosystems, accounting for higher SOC than native forest (Fallow) (Yakimenko, 1998). A study conducted by Wei *et al*. (2009) in the Northern Loess Plateau of China found that the distribution of extensive root systems could contribute to an increase in SOC under native grasslands.

However, the lowest carbon content in fallow compared to other land use types following a previous study by Angers *et al*. (2011) could be that greater part of the SOC measured was not bound to minerals and was unprotected from emissions and erosion.

With respect to SOC level at various soil depths under each land use type (Table 2), the finding presented comparatively higher carbon content values in the upper layers of soils but decreased with depth amid all land use types as reported in several other studies (Kandagor, 2015; Kumar *et al.*, 2015; Sharma, Hussain, Sharma & Arya, 2014; Zádorová *et al*., 2015; Afele, Dawoe, Abunyewa, Afari-Sefa & Asare, 2021). The result revealed significant changes in SOC distribution with soil depth, hence, exonerating the findings of Solomon, Fritzszhe, Lehmann, Tekalign, and Zechal (2002) and Lemenih, Karltun, and Olsson, (2005, a). The assertion that "the deeper the depth, the less the carbon sequestration" for example, SOC was greatest at 0-15 cm depth whiles 30-45 cm depth recorded the least (Table 2). The finding corroborated Soussana and Lemaire (2014) and Orgill *et al*. (2014) who found 40 % of SOC to be in the topsoil. FAO (2015) report equally disclosed that over twenty per cent of global land surface shows high values of C stored in the topsoil. This means that topsoil is more active in sequestering carbon from the atmosphere (Guo & Gifford, 2002). The presence of high concentration of SOC in the topmost layer (0-15 cm) especially in bare soils where carbon is predominantly labile in nature is prone to higher rate of decomposition and loss of large quantities of carbon higher than that of the subsoil at long run (Veldkamp, Becker, Schwendenmann, Clark & Schulte-Bisping, 2003).

Furthermore, the introduction of deep-vegetation into shallow root systems can affect the vertical distribution of SOC fractions (Heile *et al.*, 2010) and potentially store C in the deeper soil layers; for instance, where grasslands are replaced with shrubs (Jobbágy & Jackson, 2000; Allen *et al*., 2016). Cardinael *et al*. (2017) and de Moura Oliveira *et al.* (2018) found that introducing pasture could increase/ preserve SOC at lower depths within the soil's environment. This explained the substantial quantities of carbon at lower depths (15-30 cm and 30-45 cm). This could probably be attributed to the low rate of decomposition and the accumulation of SOC transferred from the surface soil via leaching (Girmay, Singh, Mitiku, Borresen & Lal, 2008) and coconut and oil palm rooting activity in the plantation (Kumar *et al.*, 2015).

The presence of SOC in shallow depths indicated that these layers are equally important sinks in terms of conserving SOC for a long time (Harper & Tibbett, 2013). These stores can be important for overall C budgets and C entry strategies (Jobbágy & Jackson, 2000).

Relationship between SOC and other soil properties

The results showed that there was a SOC consistently significantly negatively associated with bulk density and $H^+ + Al^{3+}$ at all depths (Table 5 and 6). At 0-15 cm depth, SOC positively correlated with majority of properties except for texture where no significant correlation was observed. At 15-30 cm depths, SOC had no correlation with sand (%) and clay (%) but positively correlated with many of the properties. Soil organic carbon showed no significant correlation with clay and sand fractions but positively correlated with the remaining properties at 30-45 cm depth. In the arable SOC positively correlated with moisture content, $H^+ + Al^{3+}$, AP, and Mg^{2+} but bulk density; however, had no significant correlation with majority of the properties. For the fallow land SOC only correlated with pH, $H^+ + Al^{3+}$ and Ca^{2+} but did not significantly correlate with the remaining properties. In the plantation, SOC significantly inversely correlated with total N, Ca^{2+} and Mg^{2+}; positively with AP and K^+ but had no significant association with other properties (Table 6). In the pasture, SOC positively correlated with AP, K and $H^+ + Al^{3+}$ but inversely with Ca^{2+} and Mg^{2+} only.

This results confirmed Gülser, Ekberli, and Candemir (2016) assertion that there is an inverse relationship between SOC concentration and bulk density of soil. The higher SOC concentration recorded in plantation field could be attributed to low soil bulk density coupled with high clay content of the soil and this confirmed trends in previous works (Chaudhari *et al.*, 2013; Saiz *et al.*, 2012; Prempeh, 2015). For instance, Zhou, Zhou and Wang (2003) recorded SOC content of 3.18 % (17.55 kg C m^{-2}), 0.82 % (7.25 kg C cm^{-2}) and 0.37 % (2.99 kg C m^{-2}) for bulk density of 1.13 g cm^{-3}, 1.24 g $cm^{-3,}$ and 1.25 g cm^{-3} respectively for soils at northern China. Soils having high clay with corresponding low sand content tend to store relatively more SOC, which may be explained by the formation of a passive carbon pool via the adsorption and aggregation of SOC by clay minerals (Saiz *et al.*, 2012). This implies that the plantation field with the higher mean SOC has the potential to increase the stability of soil aggregates, water retention capacity, water availability for plants, soil biomass, water infiltration, and microbial and macrofaunal activity and cation exchange capacity (Blanco-Canqui *et al.*, 2013).

In general, the loss of organic carbon in the non-plantation lands especially in the fallow if not checked may degrade these land use systems. Mean SOC in these land use types indicated that more efforts to enhance SOC retention may be the surest way to put in place in order to fight soil infertility (degradation), eradicate poverty, eliminate hunger and mitigate climate change and its unfavourable impacts. Adopting improved pasture management (stock number optimization, rotational grazing and fertilization) could increase carbon in pastures (Guo & Gifford, 2002). Implementation of other options such as the introduction of forage species on marginal and other lands and the creation of forage grasses on bunds are essential to minimize grazing pressure and increase the potential for C sequestration from pastures (Toru & Kibret, 2019).

Moreover, higher SOC content could bind tightly Al ions and reduce their activity in the soil solution and thereby increase pH and reduce acidity (Bore & Bedadi, 2015). The situation is controlled by the declining biomass from pruning trash and reduced weed proliferation against constant mineralization rate on the biomass balance. The fresh weeds and pruned biomass tend to auto degrade green manure when soil moisture conditions are favourable.

Furthermore, it was found that the distribution of all soil properties studied were affected by land use types. The distribution of most (77 %) of these properties at soil depths differed significantly. It was also found that the interaction of land use type and soil depths had significant influence on the distribution of most of these properties including SOC (Table 1 and 2).

In conclusion, the variability in soil properties over the entire study field may be due to intrinsic (soil-forming processes) e.g uneven distribution of parent materials and extrinsic factors such as soil management practices, climatic factors and land use types.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Stratified random sampling technique was used for collecting soil cores at specific sampling points and layers comprising 3 cores per sample scooped within each sampling depth. Georeferenced undisturbed soil samples at various mini pits (0–15 cm, 15-30 cm, and 30-45 cm) from the four strata (land use types) selected were randomly collected separately for bulk density, moisture content and other soil properties for laboratory analysis. Geographic Positioning System (GPS) device was used in recording coordinates of each sampling point. Soil organic carbon, soil texture (sand, silt, clay), bulk density, moisture content, pH, total nitrogen, available phosphorous, exchangeable cations (exchangeable potassium, calcium and magnesium) and exchangeable acidity were determined. The data were grouped and summarized by land use types and soil depths for statistical analysis. Mean and standard deviation were computed for each parameter in each land use type at soil depths. The data for individual land use type and depths were also subjected to one-way ANOVA (analysis of variance). Fisher's unprotected was used to separate means that were significantly different from each other at $p \leq 0.05$. Besides, statistical differences were tested using general analysis of variance (ANOVA) in GenStat Edition 12 and Minitab 19.1 version following the general linear model (GLM) procedure for Windows.

The analysis revealed that of the four types of land uses, fallow contained the smallest amount of carbon while the plantation yielded the highest. All the soil properties determined varied significantly among the land use types. Almost 34 % of the nutrients were found to be highly (CV % > 30) variable under these land use systems.

On the other hand, about 77 % of the soil properties also significantly differed at soil depth within each land use type. Based on the mean values obtained for SOC as the main soil property investigated under the current study, it can be concluded that, plantation field encourages the retention of SOC unlike the other land use types. Majority (67 %) of the properties had very weak positive correlation with SOC while about 17 % showed very weak negative correlation at various soil depths. Soil organic carbon also showed a weak positive correlation with just about 25 % of the physicochemical properties among the land use types. It was found that land use significantly determined the SOC levels among the various land use types. This clearly accounted for the high SOC in the plantation field with permanent cover, hence, an indication of soil quality. The order of land quality using organic carbon content as a measure was plantation > arable > pasture > fallow land (Table 4). It was also found that carbon content in fallow soil reflected the balance of C inputs and C losses under natural conditions.

Conclusions

The study has produced some results of practical importance to the world that can contribute to knowledge, integrated land use systems, proper land use and management, SOC management and climate control. The following conclusions may therefore be drawn.

Most (77 %) of the soil properties determined including SOC were concentrated within the uppermost layer (0-15 cm) and decreased with depth. This implies that soil properties at soil depths among these land use times were not same.

Apart from SOC, arable land was rich in most (54 %) of the soil properties including NPK.

The results also showed that SOC significantly positively correlated with about 67 % of the properties including NPK at soil depths. However, SOC had a significant inverse correlation with just about 17 % of these properties at soil depths. This means that proper management of SOC is very crucial in maintaining fertility for sustainable agriculture.

Spatially, SOC significantly positively correlated with $H^+ + Al^{3+}$, AP, MC and Mg^{2+}; pH, and Ca^{2+}; Db, AP, K^+ and $H^+ + Al^{3+}$ and AP and K^+ in the: arable, fallow, pasture and plantation fields respectively. On the other hand, SOC significantly inversely correlated with Db, in arable; $H^+ + Al^{3+}$ in fallow; and Ca^{2+}, and Mg^{2+} in both pasture and plantation fields.

It was found that land uses and soil management practices significantly regulated the fate of SOC and the other soil properties and their distributions amidst the land use types. Plantation land use type contained most of the SOC. Maintaining the plantation type is not only improving the fertility of the soil but also reverses land (soil) degradation.

Recommendations

The following recommendations were made based on the results of this study:

To improve organic carbon content in the arable field as way maintaining the fertility of the soil, it is imperative for the farm manager to increase carbon-rich materials by incorporating under subsurface.

To improve SOC in the fallow, it is recommended for the farm manager to consider replacing the field with agroforestry with proper soil management practices.

Multi-locational studies are required to assess the influence of these land use types on SOC level in Ghana.

Improved pasture management could increase carbon in the pasture land.

The study did not assess SOC sequestration or emissions rate as a function of each land use type over a given time, so further research is needed to clearly map carbon sequestration or emissions potential of these land use types.

Since there will be increasing competition for limited land resources in future, SOC fluxes cannot be viewed in isolation from other agricultural, environmental and socioeconomic needs, but through an integrated land use systems towards achieving sustainable development.

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APPENDICES

APPENDIX A

Appendix A1: Statistics of the vertical distribution of soil properties under soil depths

Soil		**0-15 cm**		**15-30 cm**			**30-45 cm**		
Properties	F pr.	LSD	CV (%)	F pr.	LSD	CV (%)	F pr.	LSD	CV (%)
MC	<.001	1.377	28.4	<.001	0.046	14.9	<.001	0.044	13.7
AP	<.001	0.495	29.9	<.001	1.184	24.9	<.001	1.179	24.7
OC	<.001	0.085	15.3	<.001	0.073	4.8	<.001	0.118	8
Clay	<.001	1.263	11.1	<.001	0.478	33.8	<.001	0.478	34.8
Db	<.001	0.045	14.2	<.001	0.806	6.2	<.001	0.848	6.6
H^+Al^{3+}	<.001	0.025	25.1	<.001	1.021	18.5	<.001	0.857	16.5
Ca^{2+}	<.001	0.262	25.2	<.001	1.049	9.5	<.001	0.98	8.6
K^+	<.001	0.012	33.8	<.001	0.255	24.8	<.001	0.234	23.7
Mg^{2+}	<.001	0.189	65.4	<.001	0.151	63.6	<.001	0.074	32.1
N	<.001	0.026	54.3	<.001	0.009	27.9	<.001	0.008	23.6
Sand	<.001	0.869	6.7	<.001	0.025	21.5	<.001	0.034	25.7
Silt	<.001	0.975	19.4	<.001	0.121	24.2	<.001	0.097	24.5
pH	<.001	0.061	4	<.001	0.026	56.1	<.001	0.025	57

F pr.= F probability, LSD= least significant difference at 0.05, CV= coefficient of variation, AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, H^+Al^{3+}) (cmol$_c$ kg^{-1}).

Appendix A2*:* Statistics of horizontal distribution of soil properties under land use types

	Arable			Fallow			Pasture			Plantation		
	F pr.	LSD	CV (%)	F pr.	LSD	CV (%)	F pr.	LSD	CV (%)	F pr.	LSD	CV (%)
Db	<.001	0.039	12.1	<.001	0.062	19.3	<.001	0.04	10.3	<.001	0.039	14
MC	0.938	1.175	26.3	0.938	1.175	26.3	0.899	1.01	23	0.899	1.011	23
pH	0.007	0.083	5.3	0.007	0.096	7.2	0.003	0.09	5.5	<.001	0.085	5.5
AP	<.001	0.485	17.2	<.001	0.448	49.3	0.002	0.6	41.5	<.001	0.412	50.1
Sand	0.35	0.827	4.6	0.438	0.826	6.8	0.370	0.84	6.8	0.465	0.880	9.4
Silt	0.006	0.966	24.1	0.006	0.931	16.1	<.001	0.92	20.2	0.002	0.997	14.9
Clay	0.113	1.103	14.5	0.033	1.064	9.2	0.052	1.09	8.7	0.09	1.162	8.6
Ca^{2+}	0.011	0.392	13.9	0.848	0.177	48.2	0.824	0.19	56.4	0.658	0.179	32
Mg^{2+}	0.091	0.260	58.7	<.001	0.073	50.4	<.001	0.07	42.3	<.001	0.085	34
K^{+}	0.202	0.017	19.8	<.001	0.006	44	<.001	0.01	32.9	<.001	0.006	29.8
H^{+}Al^{3+}	<.001	0.031	38.9	<.001	0.031	14.3	<.001	0.03	29	<.001	0.016	27.9
OC	<.001	0.127	22.1	<.001	0.079	23.4	<.001	0.08	23.6	<.001	0.112	16.6
N	0.438	0.025	43.5	0.416	0.024	69.2	0.049	0.01	37.1	0.893	0.0363	62.2

F pr.= F probability, LSD= the Fisher least significant difference at 0.05, CV= coefficient of variation, AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, H^{+}Al^{3+}) (cmol$_{c}$ kg^{-1}).

Appendix A3: Pearson's Correlation Coefficient of soil properties distribution under Arable Land

Soil properties	OC	N	Db	MC	AP	pH	Sand	Silt	Clay	Ca^{2+}	Mg^{2+}	K^{+}	$H^{+}Al^{3+}$
OC													
N	0.107												
Db	-0.128	-0.014											
MC	0.138	0.044	-0.058										
AP	0.257	0.016	-0.054	0.057									
pH	0.093	0.096	-0.026	0.027	0.037								
Sand	0.029	-0.077	0.068	0.046	0.070	-0.165							
Silt	-0.083	-0.178	-0.042	-0.181	-0.155	-0.196	-0.264						
Clay	0.058	0.216	-0.012	0.130	0.088	0.297	-0.517	-0.689					
Ca^{2+}	0.103	0.035	-0.102	-0.031	0.090	0.002	-0.039	0.126	-0.075				
Mg^{2+}	0.134	0.099	-0.168	-0.068	0.023	-0.027	0.039	0.029	-0.052	0.705			
K^{+}	0.009	0.055	0.026	0.034	-0.103	0.065	-0.061	-0.125	0.150	-0.299	-0.077		
$H^{+}Al^{3+}$	0.141	-0.200	-0.066	0.061	0.086	-0.226	-0.140	-0.047	0.146	-0.044	-0.145	-0.059	-

AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}*), MC= moisture content (%), N=total nitrogen (%), exchangeable cations (*Ca^{2+}*,* Mg^{2+}*,* K^{+}*,* $H^{+}Al^{3+}$*) (*$cmol_{c}\ kg^{-1}$*)*

Appendix A4: Pearson's Correlation Coefficient of soil properties distribution under Fallow Land

							Soil Properties						
	OC	**N**	**Db**	**MC**	**AP**	**pH**	**Sand**	**Silt**	**Clay**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**H^+Al^{3+}**
OC													
N	-0.110												
Db	-0.003	0.027											
MC	0.099	-0.169	-0.159										
AP	-0.018	0.004	0.046	0.015									
pH	0.191	0.040	0.008	-0.041	0.146								
Sand	0.084	-0.121	0.075	-0.117	0.047	-0.062							
Silt	-0.027	-0.108	-0.054	0.156	-0.167	-0.205	-0.271						
Clay	-0.042	0.189	-0.010	-0.052	0.110	0.227	-0.532	-0.670					
Ca^{2+}	0.197	0.225	0.046	-0.106	-0.165	0.066	0.078	-0.052	-0.013				
Mg^{2+}	-0.015	0.187	-0.050	0.037	0.030	-0.149	0.064	0.129	-0.161	0.540			
K^+	0.061	-0.013	-0.070	0.196	0.065	0.104	-0.096	-0.166	0.219	-0.046	0.148		
H^+Al^{3+}	-0.212	0.023	0.102	0.072	-0.153	-0.216	-0.159	0.037	0.089	-0.151	-0.204	0.017	-

AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}*), MC= moisture N=total nitrogen (%), exchangeable cations (*Ca^{2+}*,* *Mg^{2+}, K^+, H^+Al^{3+}) (cmol$_c$ kg^{-1}).*

Appendix A5: Pearson's Correlation Coefficient of soil properties distribution under Pasture Land

	Soil Properties												
	OC	**N**	**Db**	**MC**	**AP**	**pH**	**Sand**	**Silt**	**Clay**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**H^+Al^{3+}**
OC													
N	0.057												
Db	0.118	0.097											
MC	-0.022	0.123	0.095										
AP	0.253	0.037	0.016	0.043									
pH	0.097	0.08	-0.061	0.037	0.067								
Sand	-0.002	-0.099	0.093	0.063	0.097	-0.162							
Silt	0.098	-0.115	-0.121	-0.173	-0.224	-0.222	-0.235						
Clay	-0.084	0.173	0.033	0.1	0.12	0.312	-0.557	-0.676					
Ca^{2+}	-0.646	0.081	-0.116	-0.031	-0.269	0.087	0.094	-0.051	-0.027				
Mg^{2+}	-0.308	0.019	0.084	0.072	-0.078	-0.168	0.083	0.148	-0.189	0.554			
K^+	0.245	0.017	0.227	0.099	0.086	0.06	-0.132	-0.159	0.234	-0.036	0.17		
H^+Al^{3+}	0.142	-0.083	-0.026	0.103	0.101	-0.242	-0.132	-0.064	0.155	-0.698	-0.604	-0.09	-

AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, H^+Al^{3+}) (cmol$_c$ kg^{-1}).

Appendix A6: Pearson's Correlation Coefficient of soil properties distribution under Plantation Land

	OC	**N**	**Db**	**MC**	**AP**	**pH**	**Sand**	**Silt**	**Clay**	**Ca^{2+}**	**Mg^{2+}**	**K$^+$**	**H$^+$Al^{3+}**
OC	-												
N	-0.33	-											
Db	0.11	0.04	-										
MC	-0.02	-0.08	0.06	-									
AP	0.20	0.02	-0.02	0.04	-								
pH	0.09	-0.03	-0.03	0.05	0.10	-							
Sand	-0.04	0.12	0.19	0.07	0.04	-0.25	-						
Silt	0.05	-0.12	-0.20	-0.17	-0.15	-0.12	-0.25	-					
Clay	-0.01	0.01	0.03	0.10	0.10	0.29	-0.53	-0.69	-				
Ca^{2+}	-0.56	0.12	-0.09	0.01	-0.21	0.08	0.05	-0.04	0.00	-			
Mg^{2+}	-0.26	0.25	0.17	0.05	-0.06	-0.21	0.23	0.05	-0.21	0.41	-		
K$^+$	0.17	0.09	0.12	0.06	0.13	0.04	-0.05	-0.16	0.18	-0.01	0.15	-	
H$^+$Al^{3+}	-0.10	0.01	-0.05	0.14	-0.12	-0.09	-0.21	0.00	0.16	-0.20	-0.24	-0.02	-

AP=available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), %MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K$^+$, H$^+$Al^{3+}) (cmol$_c$ kg^{-1}).

Appendix A7: Pearson's Correlation Coefficient of soil properties distribution at 0-15 cm depth

	Soil Properties												
	OC	**N**	**Db**	**MC**	**AP**	**pH**	**Sand**	**Silt**	**Clay**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**$H^{+}Al^{3+}$**
OC													
N	0.304												
Db	-0.175	-0.056											
MC	0.112	-0.017	-0.207										
AP	0.151	0.156	0.197	-0.253									
pH	0.573	0.177	0.135	-0.125	0.365								
Sand	0.015	0.062	0.277	-0.243	0.791	0.088							
Silt	0.098	-0.002	-0.311	0.268	-0.58	-0.227	-0.623						
Clay	-0.072	-0.076	-0.173	0.155	-0.668	0.015	-0.904	0.229					
Ca^{2+}	0.347	0.269	0.132	-0.145	0.78	0.295	0.828	-0.411	-0.806				
Mg^{2+}	0.232	0.252	0.012	-0.051	0.387	0.152	0.415	-0.059	-0.484	0.664			
K^{+}	0.339	0.229	0.174	-0.123	0.704	0.305	0.77	-0.432	-0.723	0.852	0.462		
$H^{+}Al^{3+}$	-0.624	-0.256	-0.095	0.03	-0.3	-0.809	-0.106	0.006	0.129	-0.376	-0.365	-0.38	-

AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), %MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, $H^{+}Al^{3+}$) ($cmol_c$ kg^{-1}).

Appendix A8: Pearson's Correlation Coefficient of soil properties distribution at 15-30 cm depth

	Soil Properties												
Soil Property	**OC**	**N**	**Db**	**MC**	**AP**	**pH**	**Sand**	**Silt**	**Clay**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**$H^{+}Al^{3+}$**
OC													
N	0.161												
Db	-0.369	-0.155											
MC	0.24	0.007	-0.18										
AP	0.175	0.116	0.051	-0.101									
pH	0.435	0.211	-0.235	0.091	0.332								
Sand	-0.062	0.05	0.191	-0.224	0.796	0.076							
Silt	0.246	-0.08	-0.277	0.126	-0.602	-0.225	-0.675						
Clay	-0.066	-0.017	-0.084	0.216	-0.677	0.034	-0.899	0.284					
Ca^{2+}	0.292	0.235	-0.101	-0.109	0.764	0.289	0.838	-0.468	-0.811				
Mg^{2+}	0.290	0.271	-0.216	-0.051	0.468	0.273	0.464	-0.295	-0.428	0.71			
K^{+}	0.316	0.222	-0.06	-0.087	0.809	0.347	0.834	-0.508	-0.783	0.933	0.608		
$H^{+}Al^{3+}$	-0.441	-0.316	0.376	-0.082	-0.224	-0.674	-0.052	0.083	0.018	-0.371	-0.375	-0.341	-

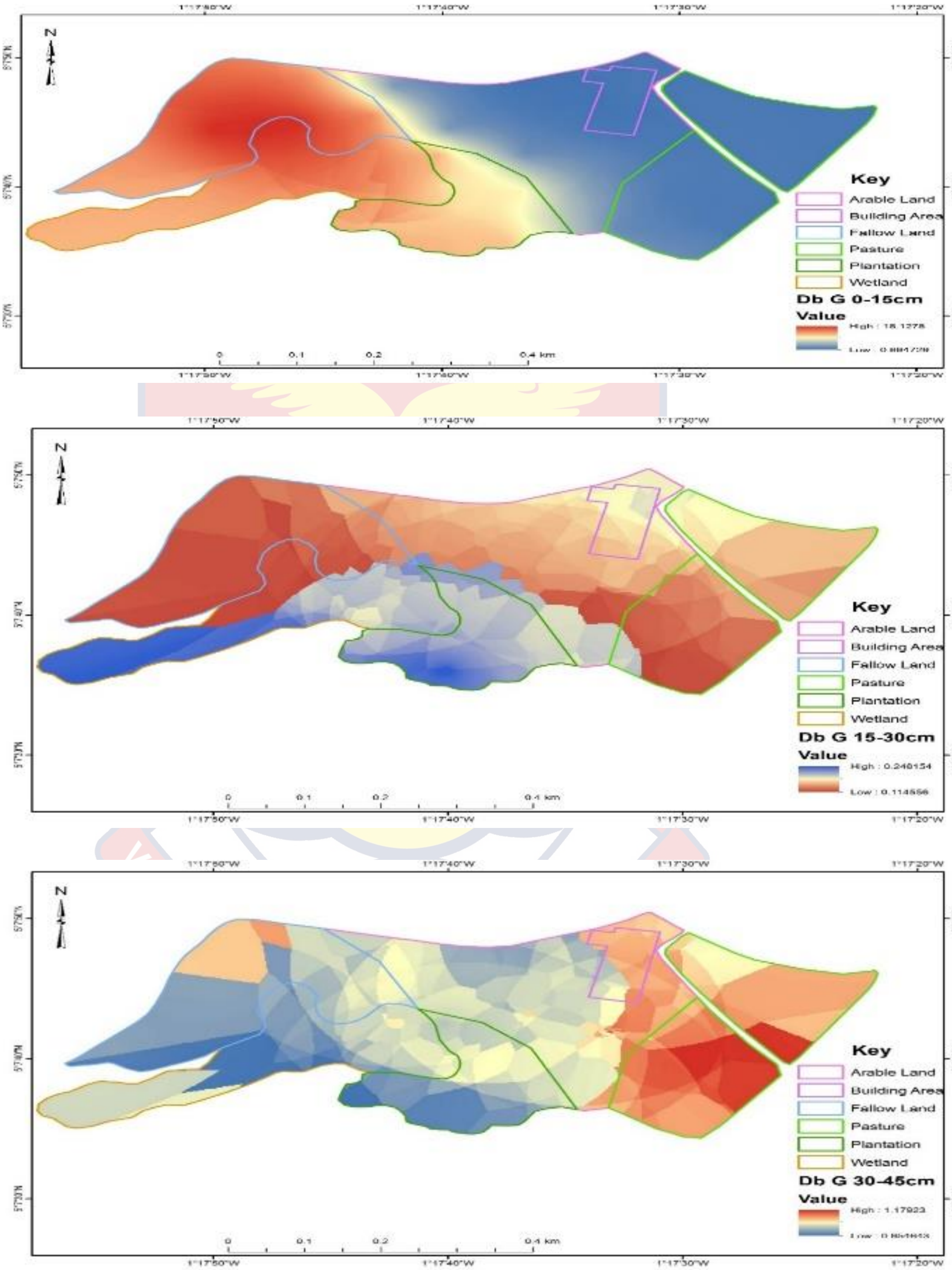
AP= available phosphorus, OC=organic carbon (%), Db=bulk density (g cm^{-3}), %MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, $H^{+}Al^{3+}$) ($cmol_c$ kg^{-1}).

Appendix A9: Pearson’s Correlation Coefficient of soil properties distribution under at 30-45 cm depth

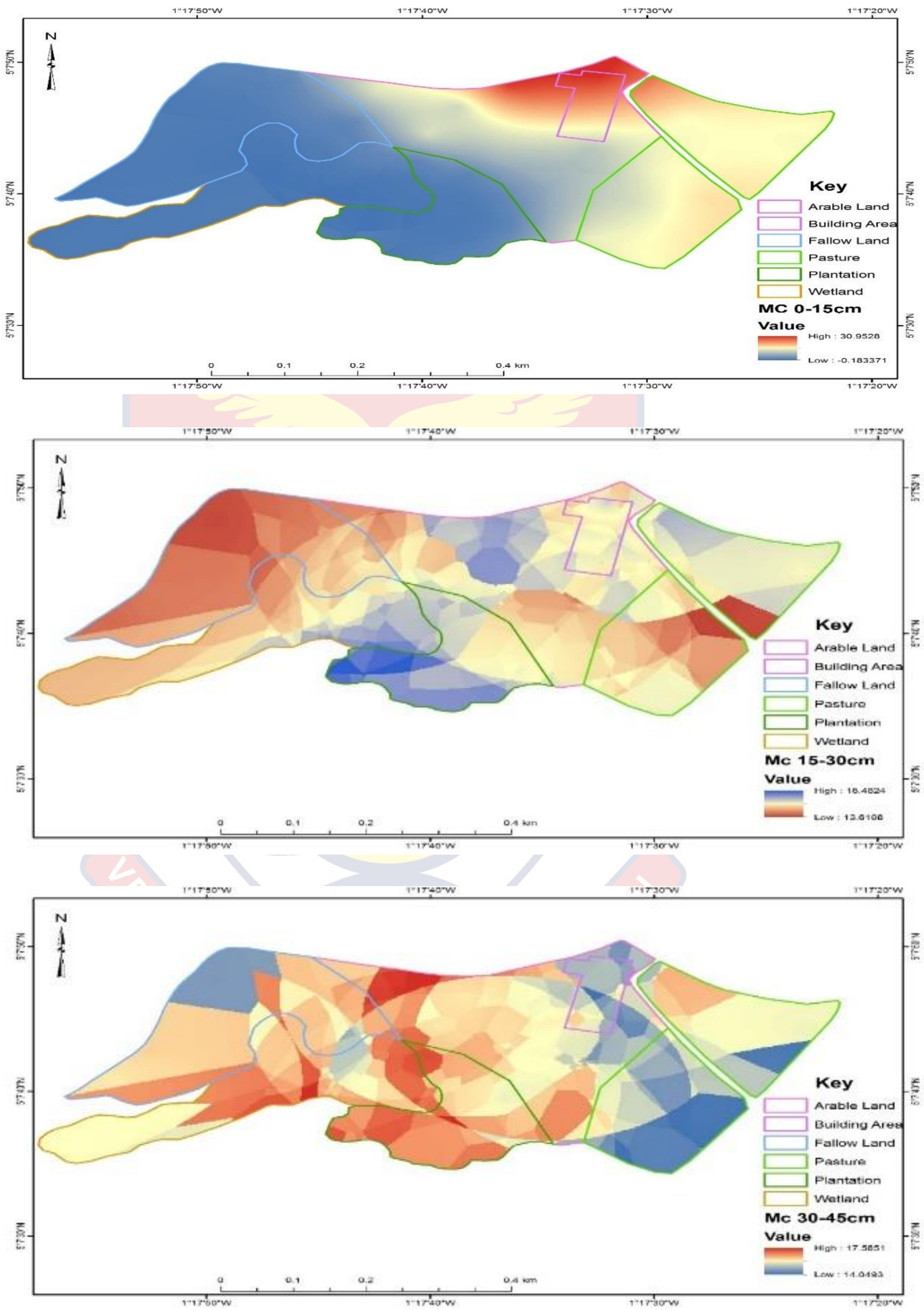
Soil Property	OC	N	Db	MC	AP	pH	Sand	Silt	Clay	Ca^{2+}	Mg^{2+}	K^{+}	$H^{+}Al^{3+}$
OC	-												
N	0.227												
Db	-0.277	-0.078											
MC	0.238	0.13	-0.231										
AP	0.167	0.118	0.169	-0.132									
pH	0.253	0.24	-0.055	0.042	0.212								
Sand	-0.035	0.06	0.248	-0.237	0.806	0.073							
Silt	0.21	-0.041	-0.345	0.197	-0.599	-0.239	-0.712						
Clay	-0.07	-0.056	-0.133	0.204	-0.727	0.038	-0.92	0.38					
Ca^{2+}	0.306	0.247	0.016	-0.117	0.774	0.306	0.831	-0.481	-0.825				
Mg^{2+}	0.372	0.338	-0.013	0.002	0.554	0.26	0.578	-0.248	-0.621	0.815			
K^{+}	0.314	0.241	0.054	-0.097	0.801	0.278	0.84	-0.534	-0.809	0.935	0.708		
$H^{+}Al^{3+}$	-0.494	-0.344	0.199	-0.067	-0.162	-0.654	0.013	-0.03	0	-0.325	-0.494	-0.291	-

AP= available phosphorus, C=organic carbon (%), Db=bulk density (g cm^{-3}), MC= moisture content (%), N=total nitrogen (%), exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, $H^{+}Al^{3+}$) (cmol$_c$ kg^{-1}).

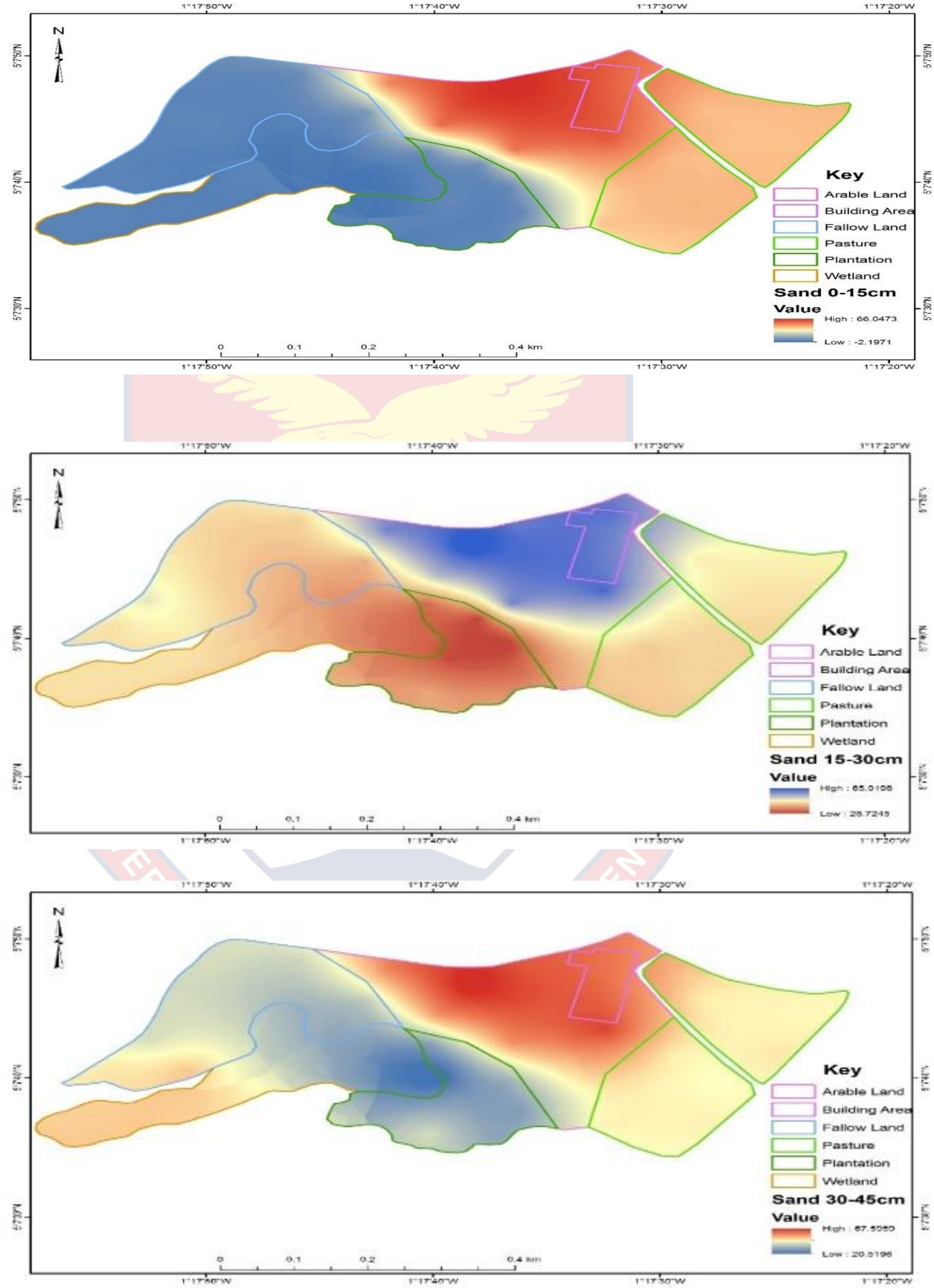
APPENDIX B



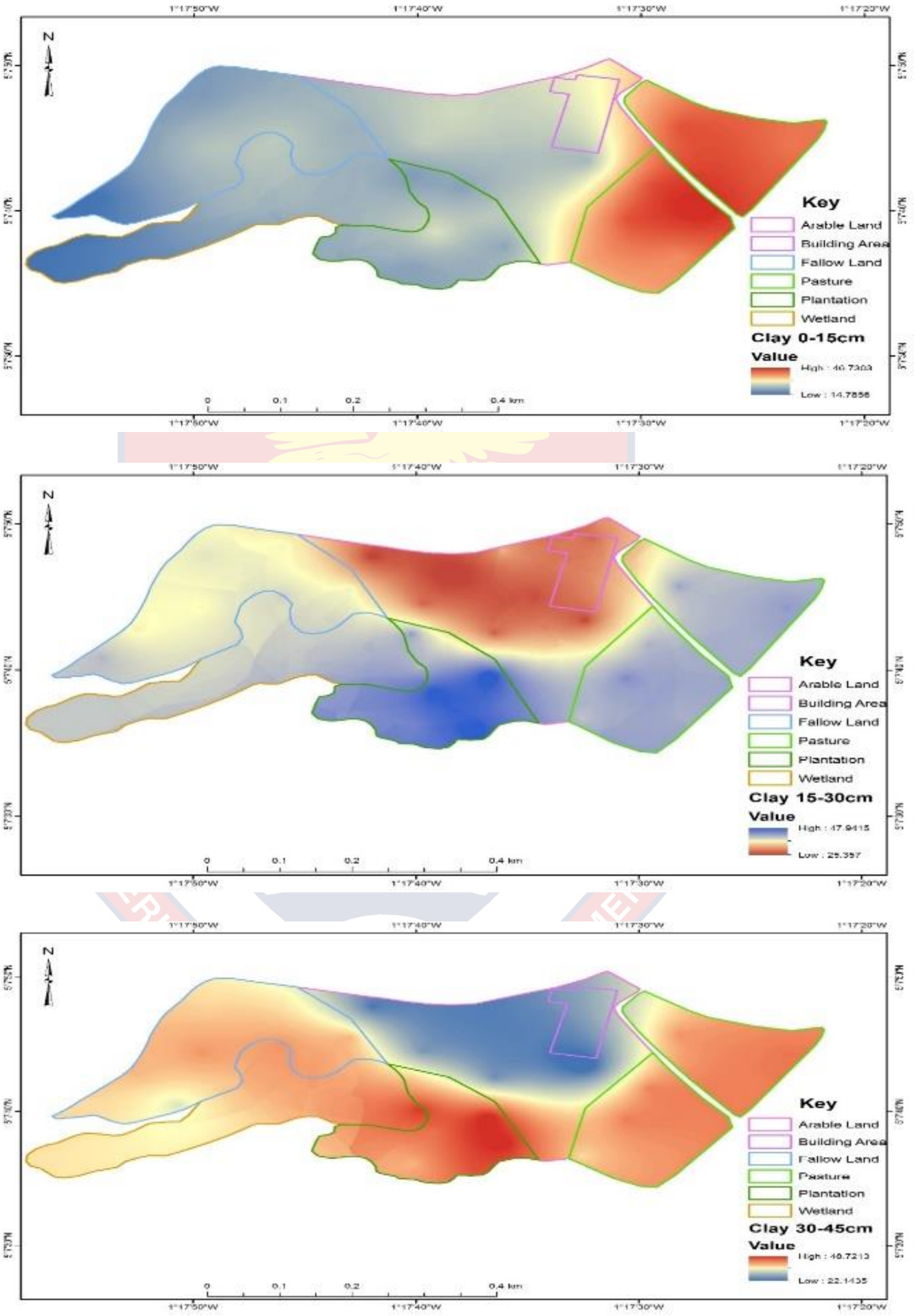
B1: Map showing spatial distribution of bulk density (g cm^{-3})



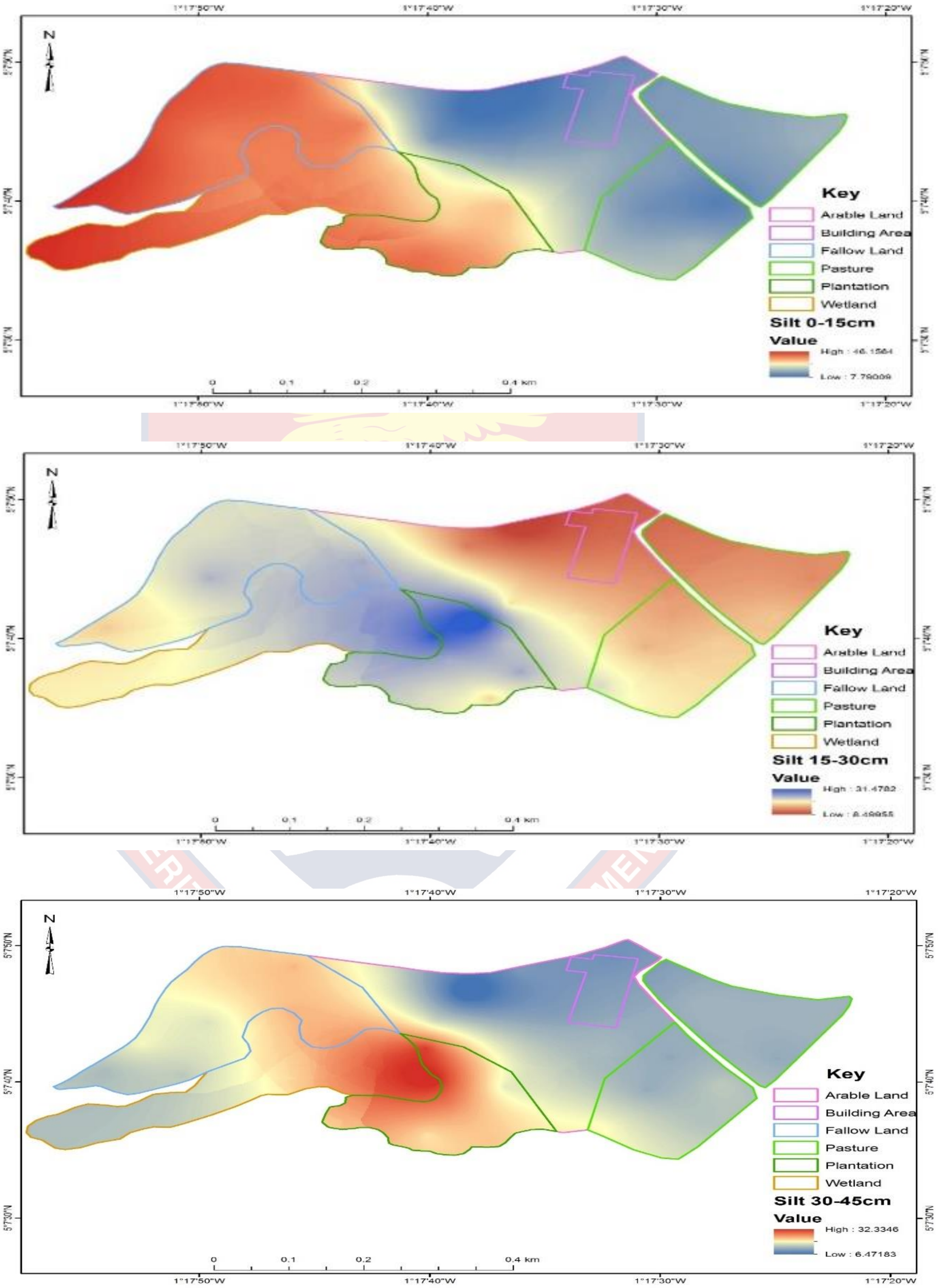
B2: Map showing spatial distribution of moisture content (%)



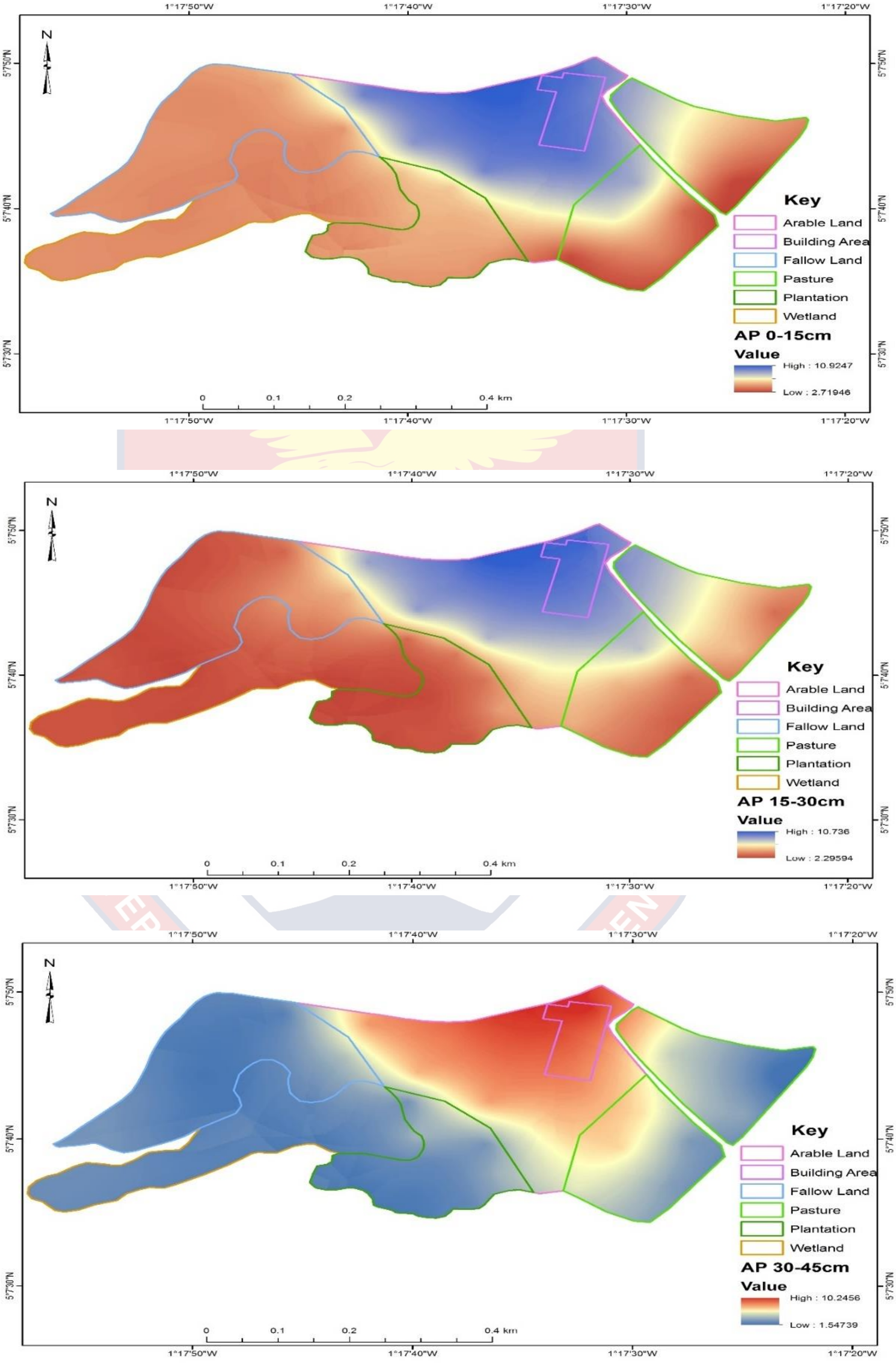
B3: Map showing spatial distribution of sand (%)



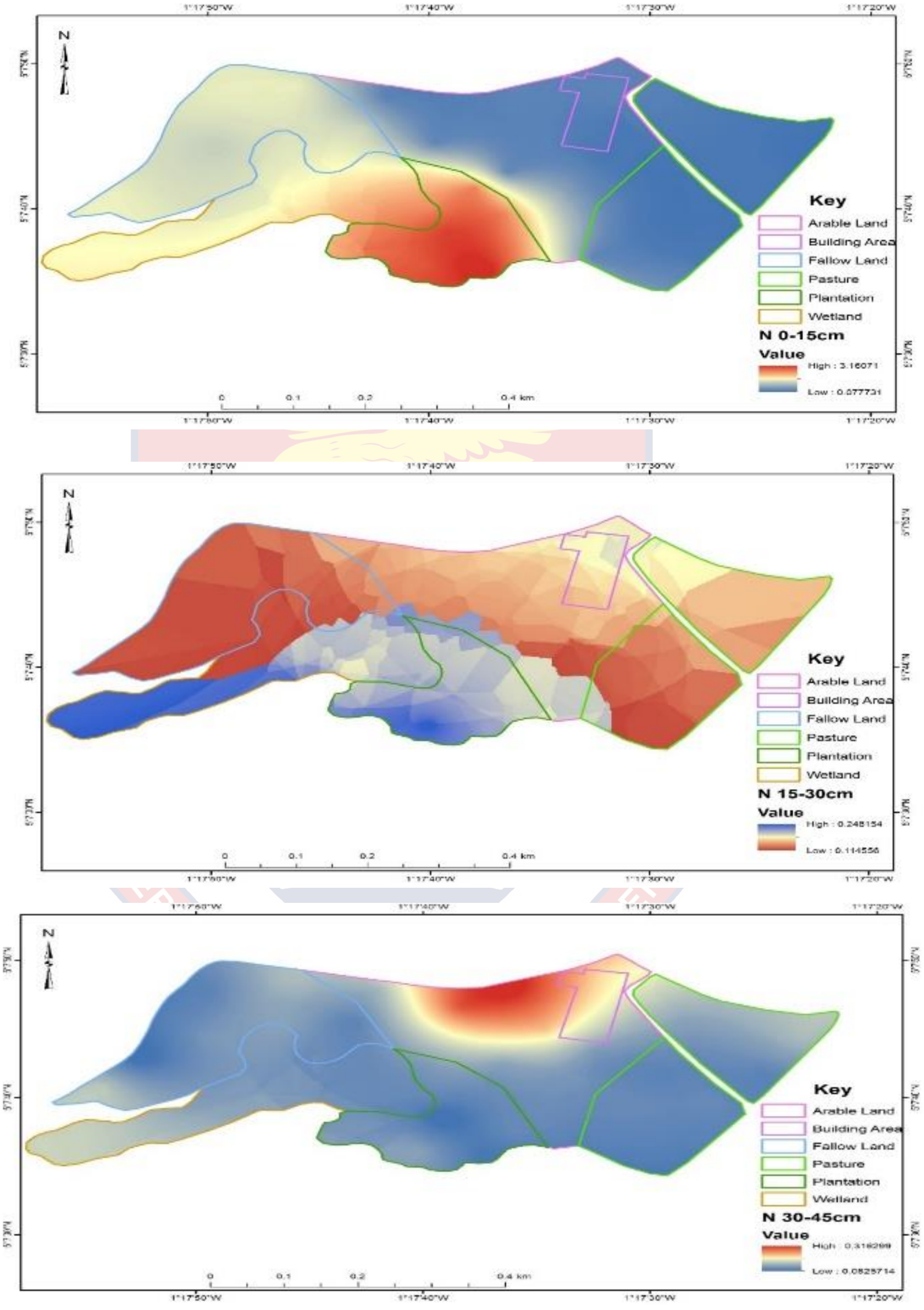
B4: Map showing spatial distribution of clay (%)



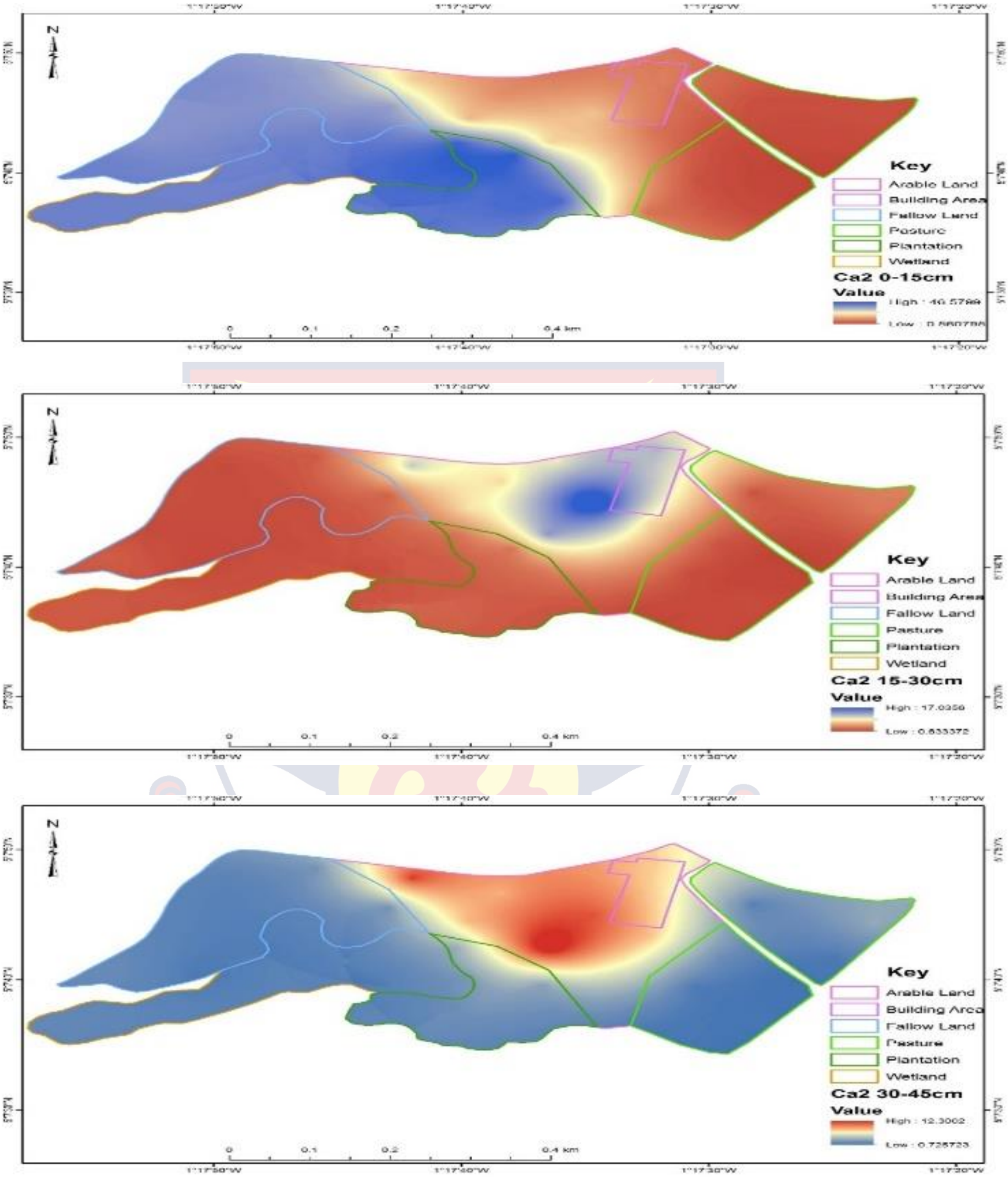
B5: Map showing spatial distribution of silt (%)



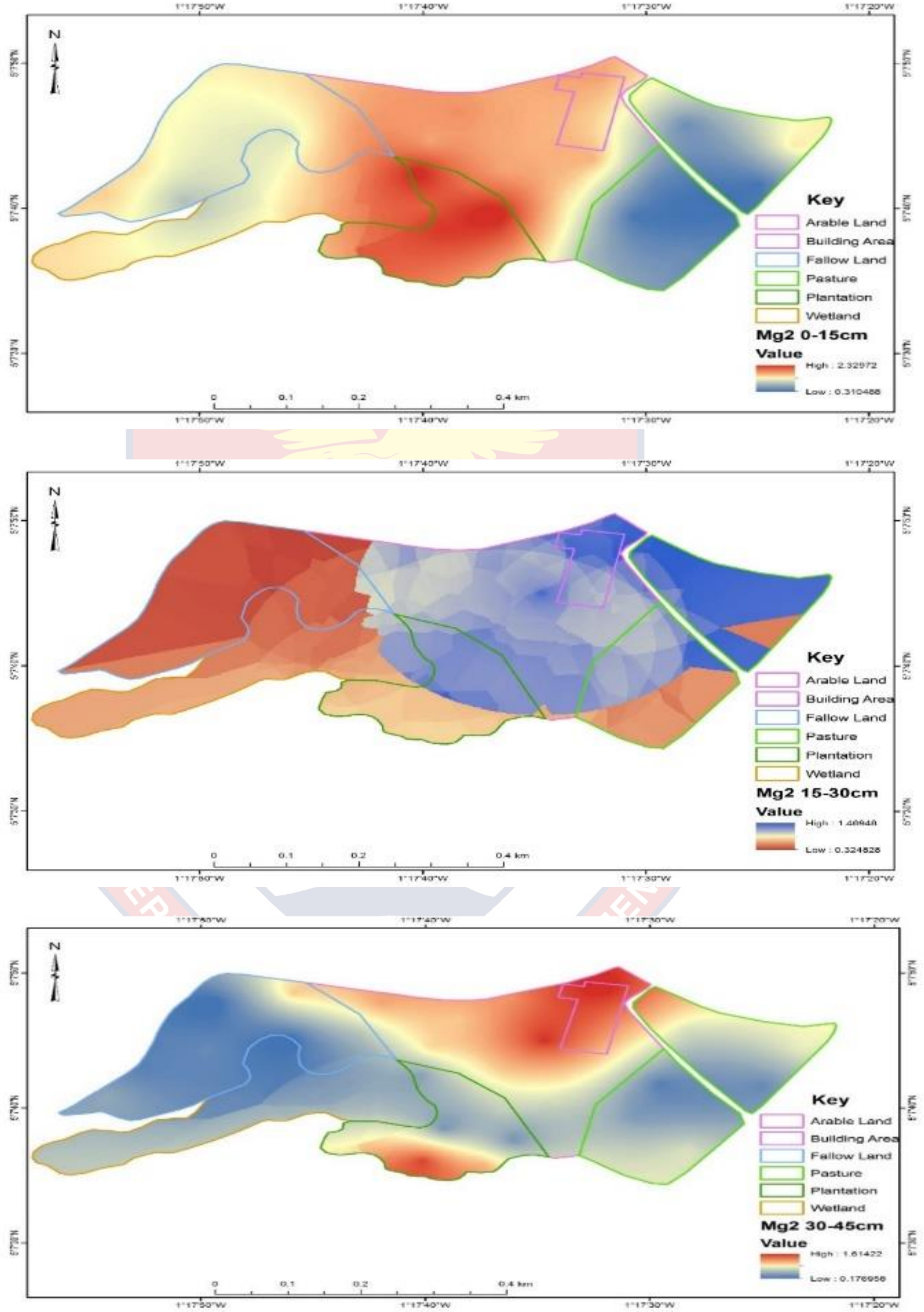
B6: Map showing spatial distribution of available phosphorus



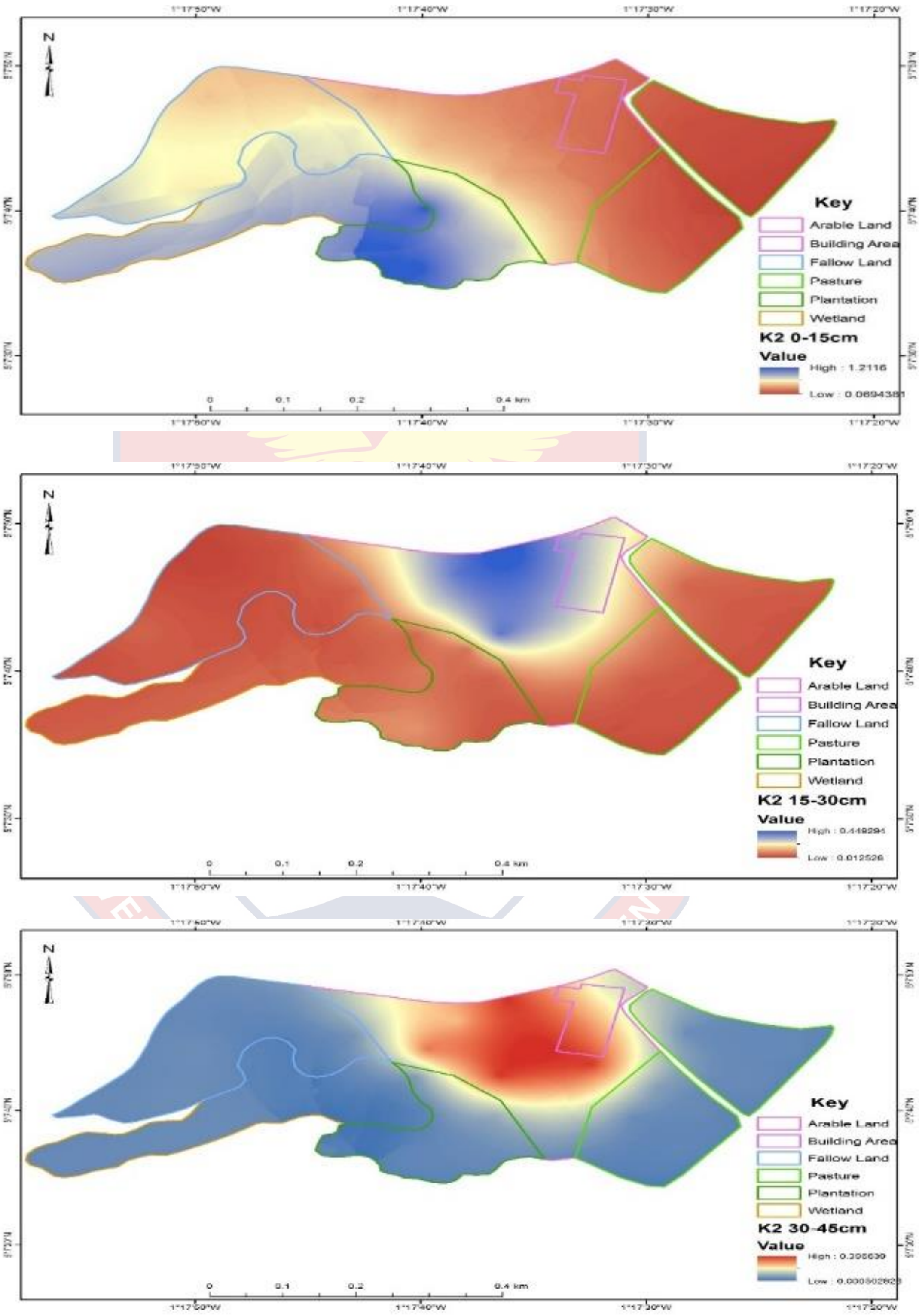
B7: Map showing spatial distribution of total nitrogen



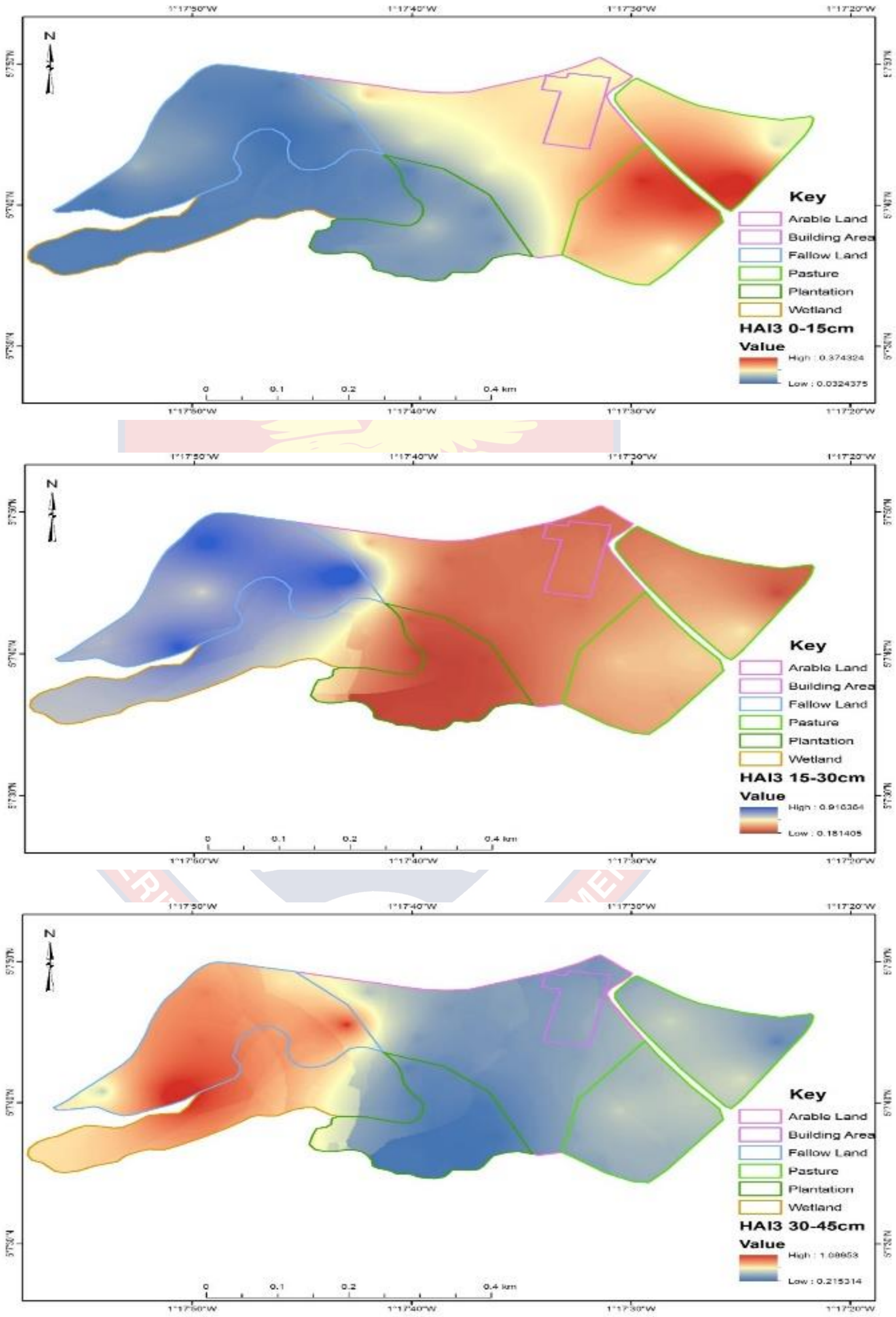
B8: Map showing spatial distribution of exchangeable calcium (Ca^{2+})



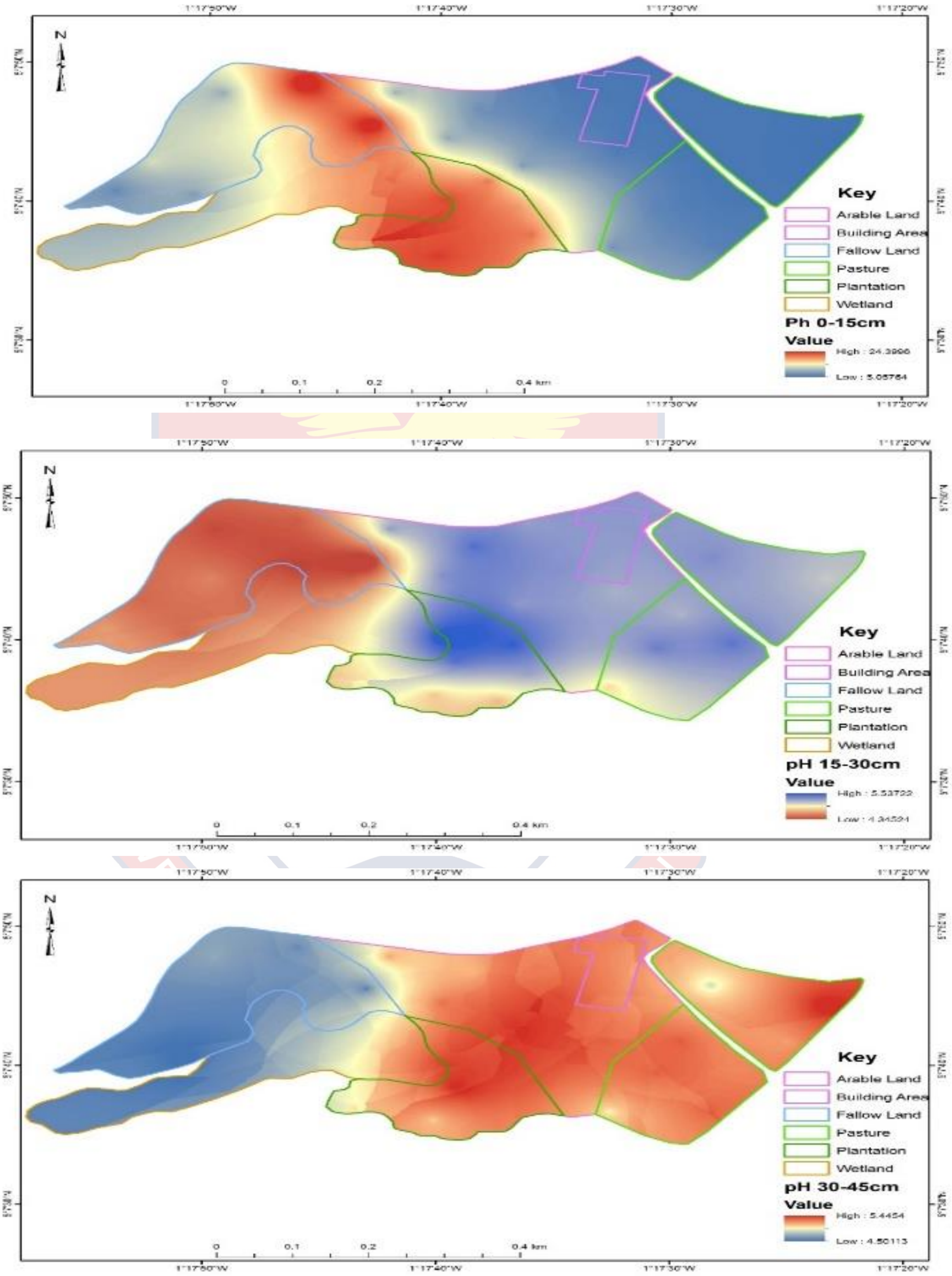
B9: Map showing spatial distribution of exchangeable magnesium (Mg^{2+})



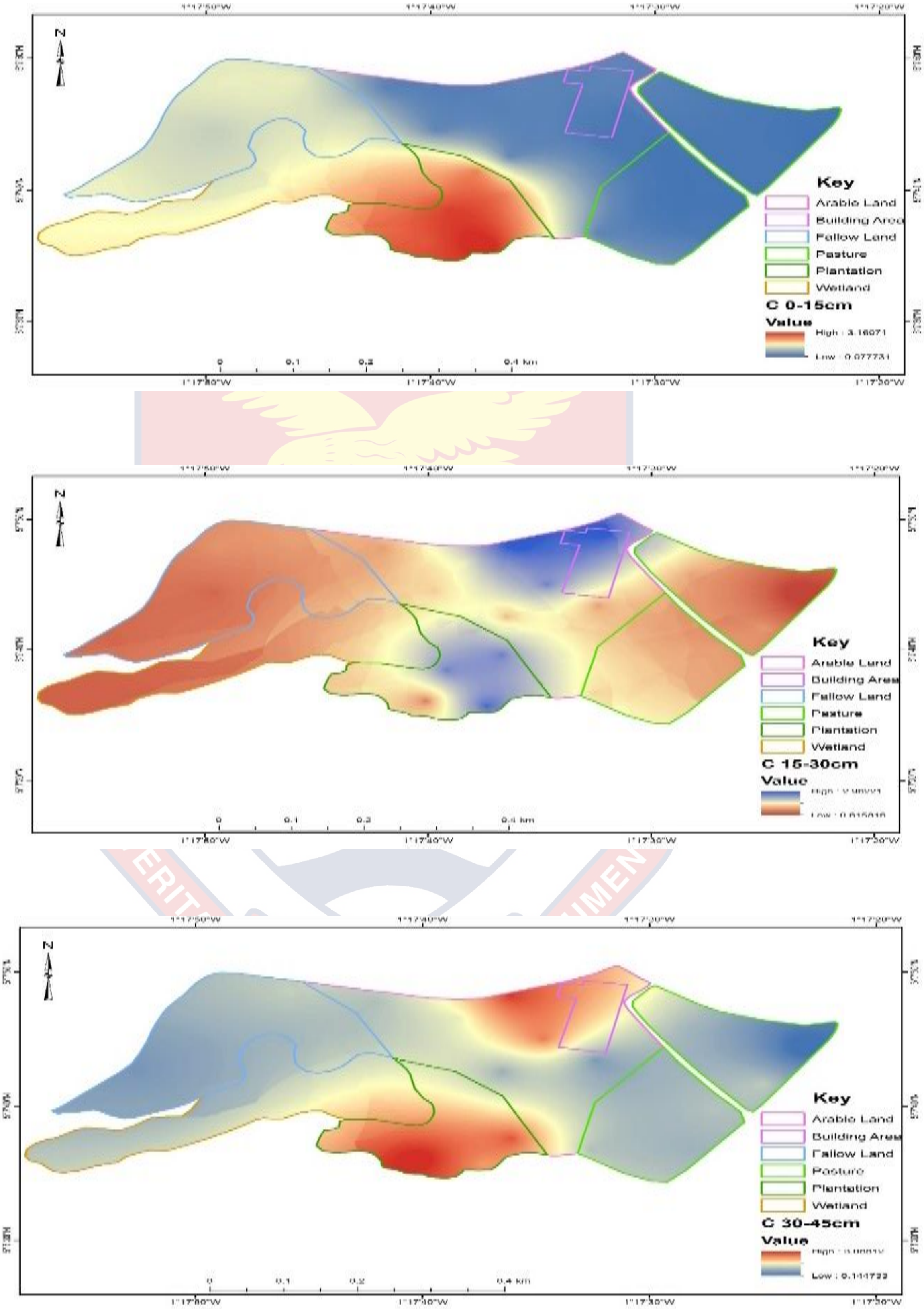
B10: Map showing spatial distribution of exchangeable potassium (K^+)



B11: Map showing spatial distribution of exchangeable acidity (H^+Al^{3+})



B12: Map showing spatial distribution of pH



B13: Map showing spatial distribution of soil organic carbon