

UNIVERSITY OF CAPE COAST

**SPATIAL VARIABILITY OF SELECTED SOIL PROPERTIES AT THE
UNIVERSITY OF CAPE COAST TEACHING AND RESEARCH FARM**

PAUL ADU-BITHERMAN

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UNIVERSITY OF CAPE COAST TEACHING AND RESEARCH FARM**

BY

PAUL ADU-BITHERMAN

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.

NOVEMBER, 2011

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 Name: Paul Adu-Bitherman

Signature: Date:

Supervisors' Declaration

We 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.

Principal Supervisor's Name: Dr. Daniel Okae-Anti

Signature: Date:

Co-supervisor's Name: Prof. P. K. Kwakye

Signature: Date:

ABSTRACT

Knowledge of soil spatial variability and the relationships among soil properties are important for the evaluation of agricultural land management practices and soil research. The study was conducted to assess the spatial variability of selected soil properties on a 2.17 ha field at the School of Agriculture Teaching and Research farm from March to October, 2010.

A stratified random sampling design was employed in the study. Samples were collected from two depths 0-10 cm and 10-20 cm at each sampling point. A total of 1,510 samples was obtained over the 2.17 ha research site. Twenty-one soil physical and chemical properties were determined on the samples. Classical and geostatistical analyses were performed on the data, using the GENSTAT statistical package.

The study revealed general deficiencies in the amounts of soil macro and micronutrients. These were attributed to random and systematic variation in consolidation, mineralization, compaction, leaching and eluviation-illuviation of silicate clays and erosion. Non-spatial dependence of soil properties was ascribed to random variation whilst spatial dependence in other properties was attributed to systematic variations. Spatial dependence in soil properties varied within 25 m.

Sampling intervals of less than 6 m and 11 m were suggested for top and subsoils respectively in order to reveal extra spatial patterns of soil properties.

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DEDICATION

To my wonderful family the Adu-Bithermans and my fiancée Joana Nana Sakyi Asiedu, for your love and patience.

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CHAPTER ONE

INTRODUCTION

Background of Study

Knowledge in variability of soil properties is essential for the management of soil resources. Such properties include organic carbon, pH, soil texture, moisture content, bulk density and porosity, which influence directly or indirectly all the other properties. Soil spatial variability affects the precision of statements about soil properties, behaviour and land use. For this reason, the determination and the establishment of spatial patterns of these properties, as well as the correlation among them is of primary importance.

The University of Cape Coast School Farm remains a source of crop and animal produce for its community and the surrounding communities around. Therefore, routine surveys on properties of soils on the farm are essential to ensure effective farm management practices. One of such investigation which has not been given much attention is the determination of the spatial variation of soil properties in this farm land. Estimates and changes of soil chemical and physical properties under different land use systems can help determine vulnerability to land degradation. Variability in soil fertility reflects past soil management practices. Once a site is put into production or otherwise disturbed, the spatial variability of the soil properties may be altered (Trangmar et al., 1987; Gaston et al., 1990). The variation in productivity

across farm fields can be categorized by delineating zones for specific management practices. Since productivity is influenced by soil characteristics, the spatial patterns of these soil characteristics could be an indication of the expected variation in productivity across the landscape.

Statement of the problem

Presently in Ghana, arable lands are continually being cultivated but not much has been done concerning qualitative information about the influence of land uses on the spatial variability of soil properties. The School of Agriculture Teaching and Research farm is of no exception. The farm was established in the mid 1960's and was known as the University Farm subsequent to a survey conducted on the soils of the University of Cape Coast in 1973 by the Soil Research Institute of the Council for Scientific and Industrial Research (Asamoah, 1973). The findings led to the establishment of a school farm which does not only serve as a source of food to the university community and its surrounding communities but also for research purposes. Since then the farm has been intensively utilised for poultry, animal rearing and crop cultivation.

However, from the time of survey till now, it can be assumed that the chemical and physical composition of these farmland soils have been modified or somehow been affected by animal husbandry and the cropping history. However, there is lack of documented data concerning the chemical status of these soils under continuous cropping for the purpose of planning an effective soil fertility management.

According to Rao and Wagenet (1985), the total spatial variability of a soil property at a managed site is a composite of intrinsic variability derived from locally variable pedological factors and extrinsic variability which is due to management. In order to propose remedial measures for soils affected by continuous farm management practices, there is the need for quantification of the changes occurring in some basic soil properties in these soils.

The goal of the research was to assess the spatial variability of selected soil properties on the School of Agriculture Teaching and Research Farm by geostatistical method.

Hypothesis

Ho: Soil properties on the farm are not spatially structured.

Ha: Soil properties on the farm are spatially structured.

Objectives of the Study

The specific objectives were as follows:

1. To determine some soil physical and chemical properties of the soils.
2. To establish correlation among the selected soil properties.
3. To assess the spatial patterns of the selected soil properties.
4. To recommend sampling designs and land management strategies which may ensure the sustainable use of the soils on the farm.

Justification

Over the years one of the ongoing challenges for pedologists and allied earth scientists has been to develop integrated system models to scale spatial

knowledge of soils from microsamples to pedons, landforms and the pedosphere. Quantification of the magnitude, location and causes of spatial variability remains an essential constituent in soil survey. Also, issues like land use and management conditions are not being accounted for in description of soil series or classifications, yet these have a large effect on soil organic matter dynamics remains a concern to pedologists.

In uniformly managed crop production fields, soil characteristics are commonly observed to have significant within-field variability (Cline, 1944). Crop management practices also contribute to the spatial heterogeneity of some soil properties, beyond which is attributable to natural processes (Cambardella and Karlen, 1999). Thus, soils under agricultural management are highly variable in chemical and physical characteristics. Due to within-field variation, uniform management of fields often results in over application of inputs in low-yielding areas and under application of inputs in high-yielding areas (Davis et al., 1996; Ferguson et al., 2002). According to Larson and Robert, (1991), site-specific management of soils and crops based on varying conditions within a field provides optimal management. These are justifications for considering spatial variability of soil properties in management decisions, with the potential result of establishing a more productive and efficient crop management systems. The findings of this study would therefore aid in planning and instituting effective soil management practices, for example, in the use of fertilizers and other chemicals alongside waste management and proper irrigation practices. The results will also predispose scientists to ways and means of capturing spatial variability in the conduct of experiments.

CHAPTER TWO

LITERATURE REVIEW

This section reviews the relevant research papers and other literature that are applicable to the topic. Issues covered include the factors and processes of soil formation, effect of land use and management on spatial variability of soil properties and geostatistical methods.

Introduction

Soil spatial variability affects the precision of statements about soil properties, behaviour and land use. Soil properties vary spatially and temporally from a field to a larger regional scale, and are influenced by both intrinsic (soil forming factors, such as soil parent materials) and extrinsic factors (such as soil management practices, fertilization and crop rotation). Many soil physical properties are known to vary temporally and are, therefore, referred to as dynamic properties (Unger, 1991; Mapa et al., 1986). Temporal variations can be caused by natural processes, or as a result of imposed management practices, such as cultivation. In the past soil survey has played a major role in the development of pedology (Simonson, 1991) and soil maps have contributed immensely to natural resource management (Moore et al., 1993). However, according to Moore et al. (1993), standard soil surveys by design do not provide detailed soil information for environmental modelling.

The heterogeneity and variation of soil properties should be monitored and quantified for a better understanding of the influence of such factors as management and pollution, and finally for leading to more efficient farming practices. Previously, changes in soil properties have been monitored through long-term field experiments, like Rothamsted Classical Experiments (Johnston et al., 1986) and the Long-term Ecological Research Program (Risser, 1991). However, this method is time-consuming and in many cases expensive. However, soil properties usually produce great variations among sample measured at several points. It is assumed that soil samples are independent from each other and the mean value is the best representative of population mean in classical statistics. However, it is well known that samples taken close together produce more related values than those far apart. That means that sample pairs produce values as a function of distance between them (Oztas, 1995). In classical statistics the magnitude of observations are usually involved in the calculations while their coordinate values of space and time are frequently neglected. Therefore, classic statistical methods may not be used safely for characterizing variations in soil properties, hence the need for another method.

Geo-statistical methods have been successfully employed in the mapping of soil properties of arable lands (Howard et al., 1994). For instance, Webster and Oliver, 1990, chose to use geo-statistical to map the soil organic carbon content of the top soil of arable land. In Ghana little attention has been paid to the spatial variability of soil properties using geographic information systems (GIS) combined with geostatistical models. However, knowing spatial variability of soil

fertility quality and its influencing factors are important to improve sustainable land use strategies (Qi et al., 2009). Buol et al. (1989), noted that until recently, most soil scientists emphasized the variation in the vertical relationship of soil horizons and soil forming processes rather than the horizontal relationship that characterize soil survey. It is therefore imperative that both directions of variations be considered as well as linking the spatial variability patterns of soil parameters to soil forming processes for a better understanding of the dynamics of soils

Factors and Processes of Soil Formation in the Tropical Zone

Factors of soil formation

Spatial variation in soils can be referred to as the causative realization of the complex combinations of soil-forming processes and is influenced by soil forming factors. These variations include parent material, climate, topography, living organisms, time, topography, the biosphere and the hydrodynamics of the profile.

Soil parent material: According to Boul et al. (1989), soil characteristics depend on the properties of the parent material from which they are formed. Soil are derived from residual sediment due to the weathering of bedrock or from sediment transported into an area by way of the erosive forces of wind, water, or ice. The influence of parent material on pedogenesis is usually related to soil texture, soil chemistry, and nutrient cycling (Anderson, 1988).

Properites of the parent material that exert influence on soil development include texture, mineralogical composition, and degree of stratification. Soils are

formed by the weathering of consolidated rock *in situ* as residual soil, saprolite (weathered rock), or are develop on superficial deposits, which had been transported by ice, water, wind or gravity. These deposits originate ultimately from the denudation and geologic erosion of consolidated rock. Consolidated material, though not a parent material, serves as a source of parent material after some physical and /or chemical weathering has taken place. Soils formed also could be from organic sediments (peat, muck) or salts (evaporites). The chemical and mineralogical compositions of parent material determine the effectiveness of the weathering forces. During the early stages of soil formation, rock disintegration limits the rate and depth of soil development. Furthermore, parent material has a marked influence on the type of clay minerals in the soil profile.

The chemical composition of the parent material determines the mineral composition of the soil formed and hence of the authigenic minerals. On Al-poor rocks, such as dunites and limestones silica released during weathering, or transferred from the degradation of topsoil, precipitates as quartz, chalcedony or opal in the absence of aluminium (Nahon, 1976; Leprun, 1979). Weathering of base parent material saprolite that is prone to more intense eluviation and oxidation at depth compared to saprolite formed on acid parent materials. In Niger, the saprolite on granite is 30-40 m thick and overlain by thick kaolinitic horizons, whereas on Birrimian Schists the saprolite is 150-200 m thick and immediately overlain by a cuirasse (Gavaud, 1977).

In savanna climates, the soils in upper horizons of upslope units tend to be acid and rich in kaolinite, iron oxyhydroxides and residual quartz sand, whereas

deeper horizons and soils of downslope units tend to be rich in clays and alkaline cations. As the transformation progresses, the latter become more abundant and extend upslope at the expense of the original kaolinite. Soils formed on transported materials tend to be more variable than those formed on bedrock in situ (Kantey and Morse, 1965; Ogoe, 1999). On the other hand, soils developed from volcanic ash have morphological, chemical and physical properties that differ from those of other mineral soils developed under similar climatic conditions (Wada, 1985). Nye (1954) noted that the differences among the catena in West Africa could be attributed to variation in the rocks, namely granites, granodiorites, gneisses and schists of the basement complex together with quartzite and schists of a later age and unmetamorphosed sedimentary rock from which they were derived.

Climate: Climate plays a very important role in the genesis of a soil. Climatic factors, mainly precipitation and temperature influence soil properties by affecting types and rates of biological, chemical and physical processes (Dahlgren et al., 1997). On the global scale, there is a correlation between major soil types and the major climatic types (Pidwirny, 2006). At regional and local scales, climate becomes less important in soil formation. Instead, pedogenesis is more influenced by factors like parent material, topography, vegetation, and time.

High annual rainfall favours vertical and lateral transport processes of ions and other dissolved substances, resulting in deep, acid, well structured soils (Dobermann et al., 1995). Biielders et al., (1996) also noted that rainfall events caused micro-relief to develop rapidly at the small scale whereas the topography

at the large scale remains virtually constant or unchanged. Yang et al. (1995) attributed micro-scale variability of soil pH among sampling sites to the impact of precipitation and plants. However, Yost et al. (1982) observed that topsoil pH to was less variable than subsoil pH and attributed the relative uniformity of the topsoil pH to the influence of rainfall. Moisture levels in most soils increase when rainfall exceeds evapotranspiration. High moisture content in a soil promotes the weathering of bedrock and sediments, chemical reactions, and plant growth. The availability of moisture also has an influence on soil pH and the decomposition of organic matter.

Climatic factors especially rainfall and temperature were found to be important parameters controlling organic matter distribution in a field although the clay content of the soil plays a part (Arrouays et al., 1995). Charles and Pain (1984), in their attempt to assess the effect of climate on weathering of volcanic materials at different elevations on soil toposequences considered rainfall and temperature regimes to represent differences weathering sequences in soils.

Topography: Topography is both an internal and external factor in pedogenesis, either influencing or being a consequence of soil evolution. Different geochemical conditions exist upslope or downslope in the same landform unit, depending upon the influence of the topography on the drainage and the hydrology of the soil cover (Boul et al., 1989). Milnes and Twidale, (1983) observed that Si-cementation fronts are related to certain low topographic situations in which silica transported for several kilometres has been deposited.

In a study of soil development along an transect in California, USA, Dahlgren et al. (1997) observed that the cation exchange capacity of the top 0 – 18 cm layer generally increased with elevation. In landforms of similar age and nearly uniform parent material, Walker et al. (1968) observed that the topographical-related soil variation can be attributed mainly to differing soil water regime commonly found with freely-draining soils in upper slope and hilltop positions and progressively less well-drained and increasingly gleyic soils in lower positions. Four soil profiles derived from volcanic ash located at elevations ranging from 800 to 1300 m on the slope of an extinct volcano in Italy were examined by Lulli and Bidini (1980) and found out that soil bulk density, clay fraction and pH increased whereas organic carbon and extractable acidity decreased with increasing elevation.

Topography generally modifies the development of soil on a local or regional scale. Pedogenesis is primarily influenced by topography's effect on microclimate and drainage. Soils developing on moderate to gentle slopes are often better drained than soils found at the bottom of valleys. Good drainage enhances pedogenic processes of illuviation and eluviation that are responsible for the development of soil horizons. Steep topographic gradients inhibit the development of soils because of erosion.

Generally, an increase in slope is associated with a reduction in leaching, organic matter content, clay translocation, mineral weathering, horizon differentiation and solum thickness (Milne, 1935). Topographic attributes and vegetation cover affect soil moisture content, surface runoff and soil infiltration.

At the top of the slope, the soils tend to be freely drained with the water table at considerable depth, whereas the soils at the backslopes and footslopes are poorly drained, with the water table near or at the soil surface. Milne (1935) recognized a recurring sequence of soil forming on slopes in undulating landscape and introduced the term catena to describe a sequence of continuous soils extending from upper slope to lower slope of the landscape. The researcher observed that each hillslope with a slope gradient is subdued to transport of soil particles and that erosion tends to be higher on convex sites with steep slopes compared to concave sites with low gradient. Also, the soils at shoulders tend to be shallower due to erosion, whereas the soils on footslope and toeslope areas tend to be thicker due to deposition.

Milne (1935) as noted that erosion reduces the thickness of the A, B and C horizons by causing the incorporating the lower horizons into the upper ones and that the sediment transport is different for each soil particle size and transport of coarse-sized particles (sand) is lowest, whereas the transport of fine soil particles (clay) and medium-sized particles (silt) is higher. Erosion occurring on a hillslope leads to higher silt content in the bottom soils compared to soils on the hillslope shoulder and that increasing the slope length allows water, which runs off the upper part of the slope to infiltrate in the lower part of the slope and to deposit eroded material carried in suspension.

Organisms: The soil and the organisms living on and in it comprise an ecosystem. Biotic factors, such as vegetation, microorganisms or animals are both internal and external factors in pedogenesis. Both micro and macro-organisms,

whose existence and activity depend on the prevailing environment, are involved in soil formation (Alexander, 1977). The presence of organic matter and the processes of biotic working affect the soil fabric and hence influence the soil moisture regime. Organic acids or chelating compounds produced during the decomposition of organic matter or as metabolic products of soil organisms are active in the transport of the released elements (Horung, 1985). Living organisms have a role in a number of processes involved in pedogenesis including organic matter accumulation, profile mixing, and biogeochemical nutrient cycling. Under equilibrium conditions, vegetation and soil are closely linked with each other through nutrient cycling. The cycling of nitrogen and carbon in soils is almost completely controlled by the presence of animals and plants. Through litter fall and the process of decomposition, organisms add humus and nutrients to the soil which influences soil structure and fertility. Surface vegetation also protects the upper layers of a soil from erosion by way of binding the soil surface and reducing the speed of moving wind and water across the ground surface.

Earthworms are the most important of the soil forming fauna in temperate regions, and are supported to an extent by small arthropods and the larger burrowing animals (White, 1987). White, (1987), also noted that earthworms are important in tropical soils, but in general the activities of termites, ants, and beetles are of greater significance, particularly in the sub-humid to semiarid savannah of Africa and Asia. Earthworms build up a stone-free layer at the soil surface, as well as intimately mixing the litter with ingested fine mineral particles (Yang et al., 1995; Dahlgren et al., 1997).

Time: Time as a factor of soil formation influences the temporal consequences of all of the factors described above. Many soil processes become steady state overtime when a soil reaches maturity. Pedogenic processes in young soils are usually under active modification through negative and positive feedback mechanisms in attempt to achieve equilibrium.

Time is an important factor in soil development in tropical regions, where weathering mantles have been evolving since the Tertiary or earlier era. Nahon and Lappartient (1977) estimated that the time required to form a profile with an Fe oxide cemented horizon has been by to be a few million years and Bardossy, (1983) estimated that for intense bauxite formation as from 1.4 to over 20 million years. Soil formation has thus operated over very long time intervals, and any changes in the factors involved will influence the nature of the product.

Various authors estimated the rate of descent of the weathering front to be between 30 and 290 cm per 100,000 years (Leneuf, 1959; Hervieu, 1968; Gac and Pinta, 1973; Trescases, 1975; Boulangé, 1984). These rates are high compared to the probable length of soil evolution in much of the tropics (Butt, 1992). Accordingly, with time soils may have descended through several lithologies.

Processes of soil formation

A large number of processes are responsible for the formation of soils. At the macro-scale, the five main processes are ferralitization, laterization, podzolization, calcification, salinization, and gleization (Pidwirny, 2006).

Ferralitization is the removal of silica from primary minerals leading to a residual accumulation of hydroxides of iron (Fe), manganese (Mg), and

aluminium (Al) (refs). Ferralitic weathering involves a depletion of basic cations and a lowering of pH. The soil is dominated by low activity clays and hydroxides. As a result the chemical status is poor, and soils have pH dependent exchange capacity. Given the low pH, these soils typically have an anion exchange capacity leading to phosphate retention. Ferralitization causes inherent poor soils with unfavourable chemical properties for agricultural use.

Laterization is a pedogenic process common to soils found in tropical and subtropical environments. High temperatures and heavy precipitation result in the rapid weathering of rocks and minerals. Movements of large amounts of water through the soil cause eluviation and leaching to occur. Almost all of the by products of weathering, very simple small compounds or nutrient ions, are translocated out of the soil profile by leaching if not taken up by plants for nutrition. The two exceptions to this process are iron and aluminium compounds. Iron oxides give tropical soils their unique reddish coloring. Heavy leaching also causes these soils to have an acidic pH because of the net loss of base cations.

Podzolization is associated with humid cold mid-latitude climates and coniferous vegetation. Decomposition of coniferous litter and heavy summer precipitation create a soil solution that is strongly acidic. This acidic soil solution enhances the processes of eluviation and leaching causing the removal of soluble base cations and aluminium and iron compounds from the A horizon. This process creates a sub-layer in the A horizon that is white to grey in colouring and composed of silica sand.

Calcification occurs when evapotranspiration exceeds precipitation causing the upward movement of dissolved alkaline salts from the groundwater. At the same time, the movement of rain water causes a downward movement of the salts. The net result is the deposition of the translocated cations in the B horizon. In some cases, these deposits can form a hard layer called caliche. The most common substance involved in this process is calcium carbonate. Calcification is common in the prairie grasslands.

Salinization is a process that functions in the similar way to calcification. It differs from calcification in that the salt deposits occur at or very near the soil surface. Salinization also takes place in much drier climates.

Gleization is a pedogenic process associated with poor drainage. This process involves the accumulations of organic matter in the upper layers of the soil. In lower horizons, mineral layers are stained blue-gray because of the chemical reduction of iron.

Sources of Variation

The sampling and estimating of regionalized variables are done so that a pattern of variation in the phenomenon under investigation can be mapped for a geographical region. However, sources of variation can be attributed to factors such as support, parent material, random, systematic as well as directional sampling.

Support

A unique aspect of geostatistics is the use of regionalized variables that fall between random variables and completely deterministic variables. Regionalized variables describe phenomenon with geographical distribution (e.g. elevation of ground surface). Though the phenomenon exhibit spatial continuity; it is not always possible to sample every location. Therefore, unknown values are estimated from data taken at locations that are sampled. In the sampling of a continuous medium such as soil, it is necessary to define a sampling unit. The size, shape, orientation, and spatial arrangement of the sample locations is termed the support and influences the capability to predict the unknown samples. If any of the support characteristics change, then the unknown values will change. For example, if the sampling unit is a soil core and parameter levels decreases with depth, then the longer the core, the smaller is the mean concentration or level of parameter in the sampling unit. However, changes in support not only change the means of the distributions, they also change the variances of concentrations and the correlations of concentrations between sampling units. Large variances of parameter concentrations between sampling units often necessitate taking large numbers of samples or cause a compromise that results in larger than desired variances of sample estimates. In many cases, a change in the support of the sampling unit will substantially reduce the variance between sampling units and thereby reduce the variances of sample estimates. Soil is a very heterogeneous material. Samples with very small support volume (say 1 mm^3) may vary from

zero to very high concentrations, regardless of the concentrations in samples of larger volume from the same location.

Parent material

Changes, disintegrations and decompositions of different parent materials over time leads to the formation of different series of soils called the lithosequence. Due to different unique compositions of bedrock materials, soil samples collected across fields underlain by similar parent materials are expected to show less anisotropic variations in soil properties than those underlain by more than one parent material. Anisotropy refers to the soils properties on the field varying with different directions.

Random and Systematic Variation

Spatial variability can be separated into systematic and random variation with both the scale of observation and our current knowledge base determining the distribution of each component (Wilding and Drees, 1983).

Systematic variation refers to structured changes in soil properties as a function of known causes such as soil-forming factors and management. This variation can be modelled quantitatively and stochastically. Random variation on the other hand refers to unstructured short-distance or microvariability of soil properties which cannot be resolved with the sampling method chosen or for which we cannot establish clear causes. This includes sampling and analytical error. Random variations can only be modelled stochastically.

Nonagricultural activity contributes to soil variability through systematic variation such as replanting of a stream corridor to create riparian buffer zones, and roadway construction altering topography through sequential cut and- fill operations. Random variation is expressed as a result of differential erosion and sedimentation rates associated with land development activities. It is conceivable that most random variation in urban soil landscapes simply reflects the present limited level of knowledge. As knowledge of the interaction between nonagronomic human activity and urban soil characteristics increases, random variation may be identified as systematic soil variability. However, Wilding and Drees (1983) classified variations as systematic or non-systematic (random), depending on whether an orderly or recurrent pattern of change is observable or not.

Directional sampling

Nelson and Wendroth (2003), noted that variation of soil and as well as its vegetation is not the same in all directions. Conditions on fields are not uniform in all directions so movement in any direction is subject to a degree of variation. Hence, condition of anisotropy. For instance, variation of soil bulk density sampled vertically to the course of a river will differ from those sampled parallel to the river. Erosion is affected by the slope of the land, prevailing weather conditions, stratigraphy of parent materials and so on (Nelson and Wendroth, 2003). Therefore sampling in different directions on a field can also bring about variation in soil properties.

Variation of Soil Properties as affected by Land Use and Soil Management

Land use and soil management practices such as cropping system, tillage practices, conservation measures, liming and fertilizer application cause variabilities in soil physical and chemical properties. According to Goldin and Lavkulich (1988), land management such as that from changes in land ownership and in the amount and frequency of the fertilizer application superimposes its own variability onto that already present in the soil. Fertilizer application usually altered the spatial distribution of Ca, Mg, K and P such that Mg and K, in particular, applied at high rates exhibit large increases in variability and marked in distribution patterns (Nkedi-Kizza et al., 1994). It has also been observed that fertilizer application enhances leaching (Pierre et al., 1971; Pleysier and Juo, 1981).

Soil fertility varies spatially from field to region scale, and is influenced by both land use and soil management practices (Sun et al., 2003). Liu et al. (2010) reported that differences in fertilizer application, cropping system and farming practices were the main factors influencing soil fertility quality at field scale. Some studies also showed the spatial variability of soil fertility quality at regional scale in China, such as in Yellow River Delta (Liu et al., 2006), Sichuan basin (Peng et al., 2009) and alluvial plain in Yangtze River Delta Region (Darilek et al., 2009). Changes in soil fertility were also reported in small watershed in Loess Plateau (Wang et al., 2009), low hilly red soil in subtropical region (Sun et al., 2003) and the black soil region in Northeast China (Zhang et al., 2007). In other areas, Amare et al. (2005) observed spatial variability of soil

fertility on mixed farming systems in Ethiopia. Samaké et al. (2005) also reported spatial variability of soil fertility on different cultivation practices in Sahel of Mali. In Ghana, Okae-Anti and Ogoe (2006) reported on the variability of some properties of a semi deciduous forest soil.

Increased population pressure in Africa has resulted in continuous cropping without fallow or other soil conservation practices and this has caused soil degradation and nutrient depletion across the continent (Adjei-Nsiah et al., 2004; Saidou et al., 2004). Okae-Anti and Ogoe (2006) noted that the changes in variation of the soil could be physical or chemical and continuous, with no well-defined inflections in the lateral rate of change, or discontinuous, as two distinct but relatively homogenous bodies of soil adjoin. They further observed higher variation in the topsoil than in the subsoil. Other studies also showed the impacts of land use and climatic change on the variability of soil fertility quality (Wang et al., 2009; Geissen et al., 2009). In the same climatic region, the land use types and soil management practices would be the main factors responsible for soil variability in soil quality (Riley et al., 2005; Reynolds et al., 2007; Mostafa et al., 2009).

Stoorvogel et al. (1993) studied nutrient input/output studies on farm lands of sub-Saharan Africa including Ghana and noticed a decline in macro nutrients N, P and K. They stated that nutrients were removed at rates far higher than their additions. Deficiencies of N and P are common while deficiencies of K, Mg, S, Fe, and Zn occur under intensive cultivation (Kang and Fox, 1981; Cottenie et al., 1981). The continuous cultivation exposes soils organic matter to oxidising

processes, since in most cases there is a reduced biomass input (Shepherd and Soule, 1998).

Johnson (1992) reported substantial decreases in soil organic matter status following the ploughing of grassland on a silt soil. Mechanical disruption of the soil structure makes previously protected soil organic matter available for degradation and increase rates of mineralization are observed in disturbed soils (Balesdent et al., 1990). Horung (1985) acknowledged that a factor which can result in acidification of soils over the time scales considered is the removal of base cations in harvested biomass. According to Sanchez et al. (1983), burning, either of the original forest, or of the pasture is the main contributor to site variability beyond the original pre-clearing differences. Forest burning releases nutrients (Ca, Mg, K) in the ash and raises pH values (Nye and Green, 1964, Sanchez et al., 1983; Trangmar et al., 1987; Andreux and Cerri 1989).

Cultivation method and machinery type affect the relative disruption of structure and, therefore, affect the amount of N mineralized (Shepherd et al., 1996). Mineralisation of organic N in topsoil is promoted by topsoil disturbance during cultivation if moisture and temperature are not limiting (Dowdell and Cannel, 1975). Timing of cultivation also affects mineralization patterns and, therefore, availability of N for crop uptake, leaching and other processes. Vinten et al., (1992), Stokes et al., (1992) and Shepherd et al., (1996) observed that delaying cultivation in autumn significantly decreased N mineralization. Soil compaction, caused by heavy machinery or cultivating the soil reduces soil porosity. This modifies net mineralization and other soil processes such as

denitrification. In attempts to make the soil more uniform through ploughing, the soil rather becomes more non-uniform (Beckett and Webster, 1971; Rao and Wagenet, 1985, Nkedi-Kizza et al., 1994) and the spatial variability of extractable Ca, Mg, K and P across the landscape increases as a result (Nkedi-Kizza et al., 1994). According to Trangmar et al. (1987), ploughing also exposes acid subsoils, increase the thickness of A horizon and bury organic matter and lower pH.

Tillage is frequently used to modify the structural of a soil by mechanically loosening the soil surface. This loosening results in a reduction in bulk density and increase porosity and hydraulic conductivity (Zobeck et al., 1994). However, Freebairn et al., (1989) were of the view that tillage reduces surface residues, weakens soil structure, leads to the formation of soil crusts, decreases water infiltration, and enhances runoff.

Land-use systems play a tremendous role in influencing the nutrient flows and overall soil quality. Bo et al. (2003) reported that changing the land use patterns decreased the ranges for soil chemical properties and showed that all the soil properties namely pH, organic matter, available P and K were spatially structured. Osuji et al. (2010) in their work on the infiltration characteristics of soils under four different land use practices (arable crop land, bush fallow, continuously cultivated land and pineapple orchard) in Owerri, Southeastern Nigeria found out that that bush fallow land had the highest average infiltration of 264 mm/hr while arable crop land experienced the least average rate of 164 mm/hr. Nair (1984) established that agroforestry, agrihorticultural, and agripastoral systems have the potential to reduce erosion and runoff, maintain soil

organic matter, improve soil physical properties, augment nitrogen fixation, and promote efficient nutrient cycling. Land use systems that improve organic matter, soil fertility and overall chemical soil quality include alley cropping (Kang et al., 1981; Kang and Wilson, 1987; Kessler and Breman 1991), ley farming (Jaradat, 1990), and agrihorticultural and agroforestry systems (MacDicken, 1990).

Land-use systems comprising tree, crops, and pastures promote nutrient cycling. The nutrient cycling is defined as continuous transfer of nutrients that are already present within a soil–plant system such as a farmer’s field (Nair 1993; Nair et al., 1995; Buresh and Tian, 1997). Jordan (1985), however stated that nutrient cycling involves the continuous transfer of nutrients within and between different components of an ecosystem and includes processes such as weathering of minerals, activities of soil biota, and other transformations occurring in the biosphere, lithosphere, and hydrosphere. Natural forest ecosystems of the tropics represent self-sustaining and efficient nutrient cycling systems. These are “closed” nutrient cycling systems with relatively little loss or gain of the actively cycling nutrients, and with high rates of nutrient turnover within the system. In contrast, most of the agricultural systems represent “open” or “leaky” system with comparatively high nutrient losses. Nutrient cycling in agroforestry systems falls between these extremes (Nair et al., 1995).

Brye (2003) observed that particle-size fractions and water-retention characteristics were significantly affected by land use and years under continuous cultivation. The sand-sized fraction decreased and the clay-sized fraction increased significantly for the agricultural soil that had been annually cultivated

the longest. Tillage has also been shown to affect significantly the pore-size distribution index (Powers et al., 1981). Tollner et al. (1984) observed significantly less plant-available water near the surface in soils under no-tillage than those under conventional tillage. However, water retention in agricultural soil has been shown under reduced tillage and no-tillage than under conventional tillage (van Ouwerkerk and Boone, 1970; Hill et al., 1985; Datiri and Lowery, 1991; Wu et al., 1992; Hubbard et al., 1994; Azooz et al., 1996).

Hargrove et al. (1982) noted increase in concentrations of extractable Ca, Mg, P, Mn and Zn in the upper 7.5 cm of no-tillage soils in comparison with conventional tillage management and added the difference in concentrations decreased rapidly with depth in the profile. Qian et al., (1994) also observed that with soils that have been depleted of organic matter from long – term cultivation, imposition of no – tillage alters the dynamics of nutrient cycling and attributed the reason that increases in organic matter content in no –tillage surface soils enhanced downward mobility of ions due to improved soil structure.

Soil variability within woodland is greater than that in cultivated soils, probably as a result of the greater diversity in forest vegetation (including the forest litter) and forest activities such as tree-throw, differential litter accumulation and logging practices or as a result of greater homogeneity in management (Goldin and Lavkulich, 1988). The thickness of surface soil according to Ellert and Gregorich (1996) was generally more variable in forested site than that of adjacent cultivated sites whereas for the subsurface soils, the thickness was more variable in cultivated than forested sites.

Ellert and Gregorich (1996) noticed significant differences in soil bulk density between depths in pasture and cropland, but not in the forest. They observed that depending upon the increases in soil bulk density and disruption of pores by cultivation, total porosity decreased accordingly. They also observed that distribution of organic carbon, total nitrogen and available phosphorus within water-stable aggregates of soils showed preferential enrichment of these elements in the macroaggregate fraction (4.76-2.0 mm) for the uncultivated soils and microaggregate fraction (>0.25 mm) for the cultivated soils.

Scott et al. (1994) observed that bulk density and total porosity variation in the short-term, as a result of cultivation. Voorhees and Lindstrom (1984) reported that tillage affects general soil tilth and that the effects of cultivation change over time. On the other hand, other soil physical properties, such as particle-size fractions, are generally static and unaffected by imposed management practices. Arshad et al. (1996) noted that soil texture, is altered only slightly as a result of the effects of mixing by cultivation. Thus, whereas soil texture is a physical property that is not likely to change, individual particle-size fractions, especially the sand- and silt-sized fractions, may be susceptible to breakdown by repeated mechanical disruption and manipulation as a result of continuous annual cultivation. The clay-sized fraction is also susceptible either to removal by erosion or enrichment by deposition from differential erosion within a field.

The effect of land use and soil management on the distribution of physical and chemical soil properties are of importance because of its implications for site-

specific fertility management. Das et al. (1993) reported that allocation of scarce land resources, based on the capability class, to alternate land uses not only checks degradation but also increases productivity in terms of food, fuel, fodder, and fruit. Osuji et al. (2010) suggested that marginal lands that are fragile and prone to soil erosion and other soil degradation problems be reverted to bush fallow for organic matter build-up. The presence of adequate amounts of mulch cover helps maintain high soil nutrient status and high biological activity. Mulch also protects the soil against high temperatures, soil erosion, and run-off, thereby preventing the breakdown of soil structure and the resultant soil compaction and decreased permeability. Furthermore, mulching increases soil moisture retention and reduces runoff and soil erosion (Lal, 1974; Kang and Juo, 1986). More so, while crop residue is a commonly used source of organic matter, it is not the only source. Animal manure and waste vegetation are good sources of organic matter. These could be obtained locally or from commercial operations that are seeking locations to spread excess animal manure.

According to Goldin and Larkulich (1988), the interpretation of soil variability is done through the examination of the coefficient of variation (CV). Coefficient of variation (CV) as explained by Okae-Anti and Ogoe (2006) is an independent measure of relative dispersion and it is a useful tool in comparing distributions where units may be different; it is used to assess the relative variability of soil properties and it is useful in calculating the number of observations necessary to estimate the mean within a given confidence interval (Upchurch and E, 1998; Wilding, 1988). Nkedi-Kizza et al. (1994), in their work,

on the influence of soil management on inherent soil variability, observed that an attempted uniform site preparation for planting imposed non-uniform changes in extractable Ca, Mg, K, and P and stressed that ploughing and fertilizer application greatly increased the variability of extractable Mg, K and P. Studies carried out by Ellert and Gregorich (1996) on C, N, and P storage in cultivated and nearby forested soil although did not present information on spatial variability, an observation of their data showed that amounts of C and N in the surface and subsurface soils of cultivated sites were more variable or heterogeneous than the corresponding values in the forested soils. Their data, however, showed less variability of P storage in the surface and subsurface soils in the cultivated than the forested site. Using classical statistics according to Okae-Anti and Ogoe (2006) is effective by making use of coefficients of variation in describing soil variability. However Campbell (1979) warned that the comparison of the magnitude of soil variability must be done with caution, because few scientists use comparable sampling schemes. In comparing coefficient of variation (CV) of uncultivated soil with that of cultivated soil, Goldin and Larkulich (1988) observed that CVs for uncultivated soils in the upper 0–20 cm were either greater or equal to those of cultivated soils for all chemical variables except K in all sites and P in soils formed in alluvium. Gallagher and Herlihy (1963) point out that CVs may be lower after tillage than under old pasture and Ogoe (1999) also recorded that the variability of chemical properties were greater in grazed fields than in cultivated fields.

Major characteristics of spatial variation of soil properties within a field

Spatial variation is attribute-specific: Soils must be described in terms of measurable morphological, chemical, physical, or biological attributes. Each of these features may exhibit another type of spatial variation in the same field, depending on the predominant factors that cause the variability. Relatively stable (static) soil properties tend to have different spatial structures than more dynamic soil properties.

Spatial variation is scale-specific: Soils vary continuously from megascopic to microscopic levels of resolution, and there is no homogeneity at all. Even seemingly random variation has its causes. The spatial variability revealed depends on the particular scale and sampling scheme chosen.

Spatial variation is site-specific: soil forming factors and management impacts are highly diverse and site-specific. Information obtained from one area cannot be transferred to presumably 'similar' areas without thorough verification.

Spatial variation is method-specific: Variations in sample processing and laboratory methods affect how much variability is revealed.

Spatial variation is time-specific: Some soil properties change quickly over time, others change slowly. Spatial patterns at one time might be different from spatial patterns at another time, especially when management changes.

Geostatistical methods

The basic assumption of the Fisherian (classical) statistical procedure is that the observed variations are random and independent of sample location. These assumptions however, make the classical model inadequate for the

evaluation of spatially dependent variables. Soil properties have been found mostly not to vary randomly but to vary continuously in space (Webster, 1985) implying that they are spatially dependent.

Geostatistical techniques, which are based on the theory of regionalized variables (Matheron, 1971) provide a tool for the quantitative evaluation of the spatial dependent variables such as soil properties and can additionally be used to interpolate these spatially dependent variables. Where, interpolation refers to estimating the attribute values of locations that are within the range of available data using known data values.

The variogram is the central tool of geostatistics and has variously been used (Webster, 1985) to quantify the scale, direction and intensity of spatial variation and to provide information for interpolation by kriging and optimization of sampling intensity. It is also helpful in explaining the underlying factors responsible for the observed variation in soil properties.

However, evaluation of variabilities in soil properties are done using the classical statistics involving the measurement of the sample mean and measuring the variance of the sample about the mean, or by trend analysis that identifies the presence of any trend in the variability of the properties.

According to Goovaerts (1997, 1999); Webster and Oliver (2001), geostatistics has received attention in the soil and environmental sciences, as it provides a set of tools and methods for analyzing data distributed in space (e.g. measurements of soil properties) and for supporting decision-making processes in a context of uncertainty in the last decades. Spatial patterning of surface attributes

and soil properties can be a key element in shaping water and nutrient flows in semiarid ecosystems, and its identification is relevant for understanding degradation processes in these areas, and to establishing adequate management measures (Schlesinger et al., 1990).

Geostatistical methods are mostly employed in the assessment of spatial distribution patterns of soil properties. These methods are commonly used to define spatial variability and estimations of many properties in different fields. Autocorrelation and kriging analyses are applied to soil science for defining spatial and temporal variability as a function of time and location (Warrick et al., 1986; Kutilek and Nielsen, 1994; Reese and Moorhead, 1996; Bourgault et al., 1997, Goovaerts, 1999; Bocchi et al., 2000; Webster and Oliver, 2001).

Geostatistical methods are applied in two steps. In the first step, the degree of autocorrelation among the measured values of a soil property is defined and in the second step values of the property at unsampled points or areas are estimated using an advanced interpolation technique. Semivariograms and Kriging methods are commonly used for these purposes (Isaaks and Srivastava, 1989). Within the last decade, geostatistical methods are intensively used for modeling spatial variability and mapping distribution patterns of soil properties within an area (Yost et al, 1982; Trangmar et al., 1987; Miller et al., 1988; Lark, 2002).

Most geostatistical estimation and simulation approaches rely on a variogram model that quantifies the spatial variability of the soil property under study

Characteristics of the Variogram (semivariogram)

The variogram relates the similarity or difference, expressed as the semi-variance, between values at different places to their separation distance (lag) and direction. This theory is based on the assumption that the properties to be evaluated (soil properties) are locally stationary (Burgess and Webster, 1980). Given this basic assumption of stationarity, semi-variances can be estimated using the formula:

$$\gamma(h) = \frac{1}{2N(h)} [Z(X_i) - Z(X_i + h)]^2 \dots \dots \dots (1.0)$$

Where $\gamma(h)$ is the semivariogram, $N(h)$ represents the number of pairs of observation, $Z(X)$ and $Z(X + h)$ are the values of a random function representing the soil property of interest, Z , at places X , and $(X + h)$ separated by the vector h , known as the lag (Nelson, and Wendroth, 2003).

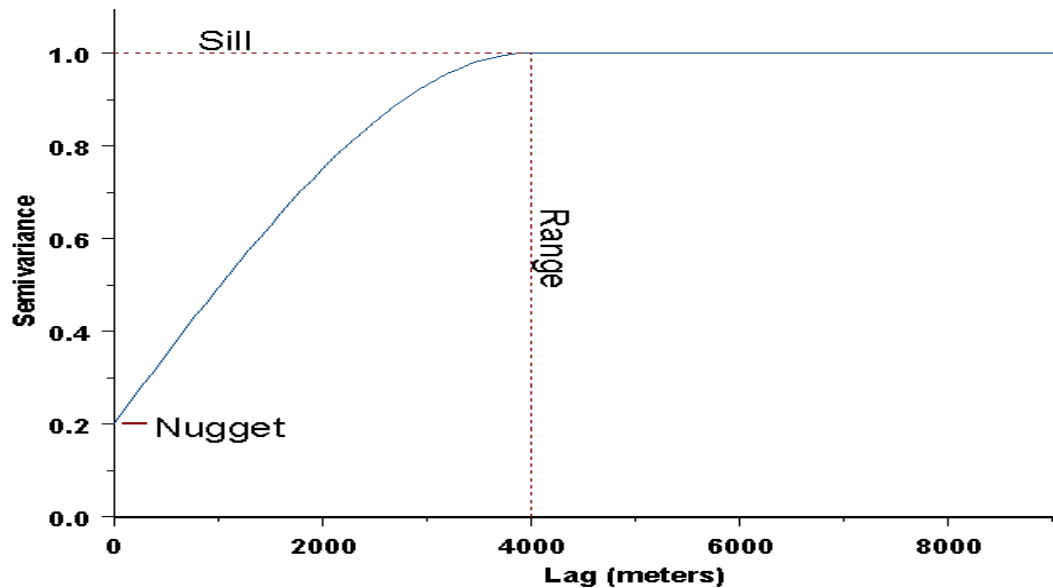


Figure 1: An illustration of plot of the semivariances as a function of distance from a point.

The semivariance at a distance $d = 0$ should be zero, because there are no differences between points that are compared to themselves. However, as points are compared to increasingly distant points, the semivariance increases till the semivariance values level off (Figure 1).

Sill: The semivariance value at which the variogram levels off. Also used to refer to the “amplitude” of a certain component of the semivariogram. For the plot above, “sill” could refer to the overall sill (1.0) or to the difference (0.8) between the overall sill and the nugget (0.2).

Range: The lag at which the semivariogram (or semivariogram component) reaches the sill value. Presumably, autocorrelation is essentially zero beyond the range.

Nugget: In theory the semivariogram value at the origin (0 lag) should be zero. If it is significantly different from zero for lags very close to zero, then this semivariogram value is referred to as the nugget. The nugget represents variability at distances smaller than the typical sample spacing, including measurement error.

Semivariograms have many different forms and shape. Journel and Huijbregts (1991) discussed theoretical models of seven different kinds of semivariograms namely the Pure nugget, Linear (Bounded), Spherical, Exponential, Gaussian, Linear (Unbounded) and Power. They classified the models into two major categories namely Bounded or Transitional and Unbounded or Nontransitional. According to them, the former occurs whenever the variance of all observations within the domain is not constant and the latter

occurs whenever the variance of all the observations remains constant throughout the domain being sampled. In other words, as the lag increases, $\gamma(h)$ continuous to increase. Therefore, nontransitional semivariograms are those variograms without a sill. The linear (Unbounded) and power models are grouped under the nontransitional semivariograms. (Nelson and Wendroth, 2003)

Equations and illustrations of some of the models

For the following equations $\gamma(h)$ represents the semivariogram function, and **a** is called the range of influence of a sample or the maximum distance over which pairs of observations remain correlated.

Bounded or Transitional

Pure nugget

$$\gamma(h) = \begin{cases} 0 & h = 0 \\ C & h > 0 \end{cases} \dots\dots\dots (2.0)$$

C= Sill

$h = h$ is the vector, known as the lag, separating pairs of observation

The nugget model represents the discontinuity at the origin due to small-scale variation. On its own it would represent a purely random variable, with no spatial correlation.

Linear

$$\gamma(h) = \begin{cases} Ch/a, & 0 \leq h \leq a \\ C, & h > a \end{cases} \dots\dots\dots (3.0)$$

C= Sill

$h = h$ is the vector, known as the lag, separating pairs of observation

Spherical, Gaussian and Exponential models

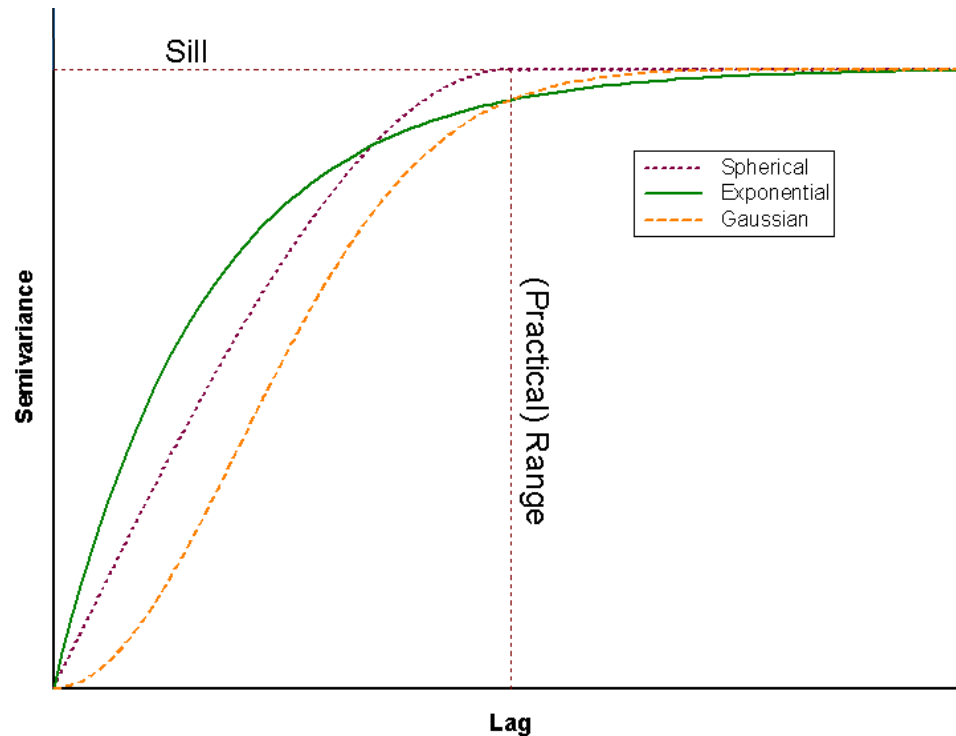


Figure 2: An illustration showing Spherical, Gaussian and Exponential theoretical models.

The spherical model actually reaches the specified sill value, c , at the specified range, a . The exponential and Gaussian approach the sill asymptotically, with a representing the practical range, the distance at which the semivariance reaches 95% of the sill value. The Gaussian model, with its parabolic behavior at the origin, represents very smoothly varying properties. (However, using the Gaussian model alone without a nugget effect can lead to numerical instabilities in the kriging process.) The spherical and exponential models exhibit linear behavior the origin, appropriate for representing properties with a higher level of short-range variability. Models with a finite sill, like the gaussian, exponential,

and spherical, are referred to as transition models and have corresponding covariance functions given by $\text{cov}(h) = c - \gamma(h)$. Where, h represents the lag distance, a , the (practical) range, and c , the sill.

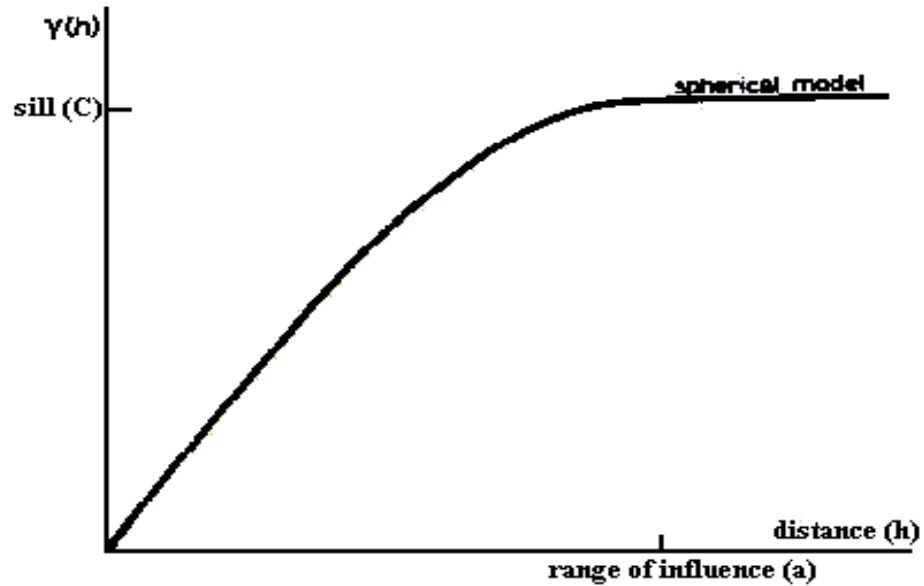


Figure 3: An example of a spherical model showing the range, sill and lag distance.

Where a is called the range of influence of a sample or the maximum distance over which pairs of observations remain correlated. C is called the sill of the semi-variogram.

$$\gamma(h) = \begin{cases} C \left(\frac{3h}{2a} - \frac{1}{2} \frac{h^3}{a^3} \right) & \text{where } h \leq a \\ C & \text{where } h \geq a \end{cases} \dots \dots \dots (4.0)$$

Exponential

In the case of Exponential the equation is given by:

$$\gamma(h) = C[1 - \exp(-h/a)], \text{ where } h \geq 0 \dots\dots\dots(5.0)$$

Gaussian

$$\gamma(h) = C\{1 - \exp[-(h/a)^2]\}, \text{ where } h \geq 0 \dots\dots\dots(6.0)$$

Unbounded or Nontransitional

Linear

$$\gamma(h) = mh, \text{ where } h \geq 0 \dots\dots\dots(7.0)$$

Where $m = \text{constant}$

Power

The power model does not reach a finite sill and does not have a corresponding covariance function. Power-law semivariogram models are appropriate for properties exhibiting fractal behavior.

$$\gamma(h) = mh^\beta, \text{ where } h \geq 0 \dots\dots\dots(8.0)$$

Where m and $\beta = \text{constants}$

Other models

There can also be the case of linear combinations of licit semivariogram models also known as licit models. Therefore, the possibility of building more complex models by the addition of the basic models described above together with different ranges and sills, thus, leading to the second meaning of “sill” discussed above. Other models like the Bessel and Pentaspherical are approximates to Gaussian and spherical models respectively.

The role/ importance of geostatistical methods in precision agriculture

Site-specific management of soils and crops based on varying conditions within a field provides optimal management (Larson and Robert, 1991). Quantifying spatial characteristics of soil properties, particularly when these properties are related to specific soil functions (e.g., crop production or water quality), can help in the understanding of soil–landscape processes and formulation of site-specific management, hence its importance in precision agriculture. Numerous research efforts have been aimed at comparing spatially variable soil characteristics to spatially variable crop yields to develop site-specific management practices (Cahn et al., 1994; Eghball et al., 2003; Chang et al., 2004).

Precision agriculture provides an opportunity to increase production and minimize potential negative impacts on the environment. Management systems under precision agriculture, must first address the measurement and understanding of variability (Pierce and Nowak, 1999). According to Mulla and McBratney (2000), the variation of soil properties with depth has been used as diagnostic layers in soil classification, and the variation in horizons has been used as the basis for the determination of borders of soil types. Agbu and Olson (1990) reported that the majority of the total variation of soil morphological and physical properties resided within the map units and not between them. For precision agriculture, concerns be focused on soil series because the variability at this level is primarily caused by changes in topography that affect transport and storage of water across and within the soil profile.

CHAPTER THREE

MATERIALS AND METHODS

This section presents a brief history as well as baseline information of the research site, the methodological approaches carried out in order to achieve the set out objectives of the research as well as materials or tools used.

Study area

The study was carried out on the School of Agriculture Teaching and Research Farm, University of Cape Coast in the Central Region of Ghana. The experimental site, about 2.17 ha, lies within the coastal shrub and thicket vegetation belt in the region (Figure 4).

Field Characteristics

Land Use History

Cropping system: There has been a considerable change in the vegetation of the project site due to intensive cultivation practices. For the past five years the site has been put into cultivation of various vegetable crops such as garden eggs, cowpea, cabbage and pepper. There is also the cultivation of cereals such as maize, roots crops such as cassava and tubers of potatoes among others.

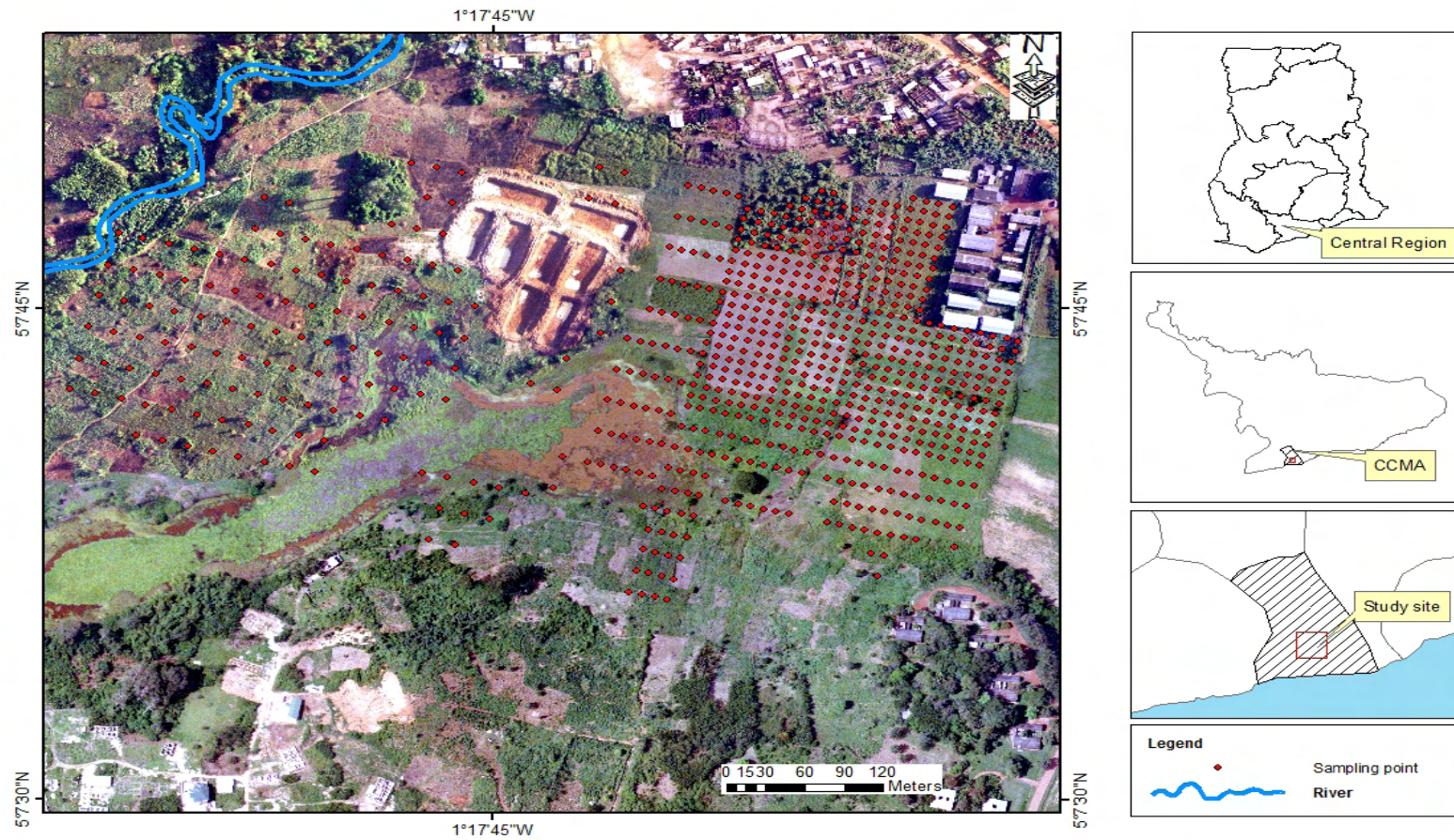


Figure 4: Aerial photograph of research site showing sampling points.

In addition, a section on the farm has been cropped to citrus for about 25 years now. The farm, established in the mid 1960's had as its objective the provision food requirement of the University Community in respect of vegetables, poultry and poultry products. In 1975, the objective was expanded to cover research, teaching and advisory role.

Cropping systems since the establishment of the farm include mono-cropping, mixed-cropping amidst soil management practices. The latter includes manuring and occasional application of inorganic fertilizers and pesticides. Irrigation has been by the sprinkler method. There are currently two pastures, of which one is not functioning at present.

Climate

There are two rainfall regimes experienced at the site of the project. There is a major season, which usually starts from March to July, and a minor season from September to November. A long dry season then follows the rainy season which starts from December to February. The mean annual rainfall is between 940 mm (Meteorological Station, Cape Coast, 2002).

There are relatively uniform temperatures that run throughout the year. The mean annual minimum temperature is 25 °C and the mean annual maximum temperature is about 29 °C. Normally diurnal variations in temperature are greater in February and March. The coolest month is August and the hottest is March (Meteorological Station, Cape Coast, 2002).

The relative humidity of the area is generally high with night and early morning values ranging from 80 % to 90 %. This falls to about 70 % in the afternoon. Generally, higher humidity values are recorded in the rainy season compared to the dry season (Meteorological Station, Cape Coast, 2002).

Vegetation

The study site is within the coastal shrub and thicket vegetation belt in the Central Region. The predominant vegetation include *Panicum maximum*, *Cynodon dactylon*, *Digitaria exiles*, *Cyperus rotundus*, *Scoroaria dukis*, *Vernonia colprata*, and *Trema guiniensia*, among others.

Relief and drainage

The relief of the site is gently undulating to rolling in the hilly areas. The height above sea level ranges from 15.2 to 30.5 m. The highest points, about 30 m high, are two hills on the southern parts of the farm sites. Most of the poorly drained valley bottom and flat plains have not been cropped due to the water logged nature of the soil.

General Description of Soils of the Farm

The soils at the experimental site were developed over Sekondian rocks which are mainly sandstones, shales, and conglomerates of Devonian age. The site, which occurs on sloping to gently undulating land, comprises the Edina, Atabadzi, Benya and Udu compound association (Appendix E). The soils are highly weathered and leached of their bases and are therefore acidic. They are dominated by low activity kaolinite clays and sesquioxides (Asamoia, 1973).

General Description of Soil Series of the farm

Edina series: The soils of Edina series consist of yellowish red, well to moderately well drained, gravelly and concretionary and are medium to fine textured. Edina series extends from the middle slopes to the summits of the hills. They cover a total surface area of 2.9 acres on the research site (Appendix D). Edina soils have been developed from a residuum of weathered

rocks and are therefore, locally referred to as sedentary soils i.e. soils formed from materials weathered *in situ*. The soils are strongly acid in reaction and generally low in nutrient reserves; cation exchange capacity is low (usually less than 15 meq/ 100 g). Phosphorus is low and nitrogen becomes deficient under cultivation. These soils are recommended for the cultivation of pineapples, cassava and maize (Asamoa, 1973).

Atabadzi series: Atabadzi series consists of yellowish to red, well to moderately well drained, medium to fine textured soils developed from colluvium on middle slopes. Thus the upper solum is free of gravels and ironstone concretions. Where the slopes are gentle, these soils may be missing from the toposequence. They are usually associated with drainage grooves on steeply sloping land. Atabadzi soils are medium to acid in the surface layer, becoming strongly to very strongly acid with depth. Cation exchange capacity is low (less than 10 meq/ 100 g). Phosphorus and nitrogen are low. Organic matter is medium but declines rapidly under cultivation (Asamoa, 1973). Crops commonly grown on these soils include maize, cassava, yams, pineapples, and vegetables. Atabadzi soils cover 9.9 acres on the research site (Appendix D).

Benya Series: consists of yellowish brown, moderately well to imperfectly drained, medium to fine textured soils developed from colluvium on gentle lower to middle slopes. These soils are medium acid to slightly acid in the surface layers becoming strongly acidic with depth. Nutrient status of the soils is similar to that of Atabadzi series (Asamoa, 1973). In the dry season they may require irrigation for the production of crops such as maize, cassava,

yams and vegetables. These soils cover 35.5 acres on the research site (Appendix D).

Udu series: consists of greyish brown to grey, poorly to very poorly drained fine textured soils developed in old alluvium on nearly flat valley bottoms. Udu soils are subject to seasonal flooding. Udu series are very strongly acidic in the surface layers becoming extremely acid with depth. Nutrients are probably low in the soils and the major problem is wetness (Asamoah, 1973). These soils can be mechanically cultivated to crops such as rice, sugarcane and dry season vegetables. The soils of this series cover 17.7 acres on the research site (Appendix D).

The Kakum-Chichiwere simple association comprises area along the Kakum River (Appendix D). The soils of the association are developed in alluvial deposits. These alluvial soils are geographically associated with a couple of Benya and Udu soil sites. The association covers 33.4 acres. It comprises the Kakum series and Chichiwere series (Asamoah, 1973).

Kakum series: This consists of brownish yellow to yellowish brown, moderately well drained, fine textured soil developed on levees. They are subject to flooding for short periods. Kakum soils cover 2.8 acres on the research site (Appendix D).

The soils of Kakum series on the farm sites are imperfectly drained, yellowish brown to brownish yellow clay loams and silt clays developed on levees along the Kakum River. Analytical data indicate that the soils are medium to low in nutrient reserves. The soils are subjected to flooding and water logging. They are therefore recommended for rice, sugarcane and dry season vegetables (Asamoah, 1973).

Chichiwere series: Consists of yellowish brown to pale brown moderately well to imperfectly drained, medium to coarse textured soils developed in alluvium on slightly raised high stream banks. These soils cover an area of 1.8 acres on the research site (Asamoah, 1973).

Field work

A preliminary survey was conducted on a section of the field using the nested sampling technique. Sampling intervals of 100 m, 30 m, 9 m, 2 m and 0.70 m were randomly applied to the field. In all a total of 120 samples were collected. Three properties, namely pH, texture and bulk density were determined for the test plot of the variograms. An average range of 20 m was arrived at.

The stratified random sampling design was used in the main study. Based on the outcome of the preliminary study a base line was selected at the site and transverse lines of 10 m apart were cut perpendicular to it such that the lines ran through the farm site to form sampling grids of 10 m x 20 m for areas that were moderately disturbed and 10 m x 30 m for portions that seemed to be less disturbed through soil management (Figure 4). The areas covered by the 10 m x 20 m and 10 m x 30 m grids were 13,020 m² and 8,680 m² respectively.

Sampling

The sampling was done between February and March 2010 and a total of 1,510 samples were collected over the 2.17 ha study site. Two standard sampling depths (0 – 10 cm and 10 – 20 cm) per sampling point were considered. Sampling was done at the nodes of the grid. Using the Geographic Positioning System (GPS) coordinates of each sampling point was recorded.

Twenty-one soil physical and chemical properties were determined on the samples.

Laboratory Analyses

The soil samples obtained were air-dried at room temperature for three weeks, crushed in a mortar and sieved through a 2-mm mesh sieve to obtain the fine earth for laboratory analyses. Laboratory analyses for soil properties were done in the research laboratory of the School of Agriculture, University of Cape Coast.

The chemical parameters measured in each sample were pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases (K^+ , Mg^{2+} , Ca^{2+} and Na^+), exchangeable acidity (Al^{3+} and H^+), effective cation exchange capacity, base saturation and micro nutrients (Cu, Fe, Zn and Pb). Also, the physical parameters measured were texture, bulk density, porosity and moisture content.

Determination of Organic carbon

The percent organic matter content of the soil samples was determined by the Wakley-Black wet oxidation procedure (Wakley and Black, 1934). One gramme of soil was wet oxidized with potassium dichromate ($K_2Cr_2O_7$) and concentrated sulphuric acid (H_2SO_4). The unreduced chromic acid was titrated against standard solution of 0.5 M ferrous sulphate, using diphenylamine as indicator. Percent organic carbon was calculated with the formula below:

$$\% \text{ OC} = \frac{\{(B - S) \times M \text{ of } Fe^{2+} \times 0.003 \times 100 \times 1.33\}}{Wt} \dots \dots \dots (9.0)$$

Where:

B = volume of Fe^{2+} solution used to titrate blank (mL)

S = volume of Fe^{2+} solution used to titrate sample

M of Fe^{2+} = molarity of ferrous sulphate solution for blank titration

Wt = soil weight (g)

0.003 = milliequivalent weight of C in gram

1.33 = moisture correction factor (mcf)

Determination of Soil pH

The soil pH was determined using 1:2.5 of soil-water ratio as described by Black (1965) by means of a digital pH-meter.

Ten grammes of sample was weighed into a centrifuge tube and 25 ml of distilled water was added; the mixture was shaken with a mechanical shaker for 30 minutes and allowed to stand for 30 minutes. The electrodes of Jenway Research pH meter-3330 were inserted into the suspension prior to an immediate vigorous shaking of the mixture and the pH value was read and recorded.

Determination of exchangeable acidity

Exchangeable acidity was determined by titration method as described by McLean (1965).

Extraction with M KCl

Five grammes of air-dry soil was weighed into a 50 ml centrifuge tube followed by addition of 30 ml of 1.0 M KCl. The content of the tube was centrifuged at 2000 rpm for 15 minutes. The clear supernatant was carefully decanted into a 100 ml volumetric flask. Another 30 ml of 1M KCl was added to the same soil sample and shaken for 30 minutes and the content was again centrifuged as done earlier on and the clear supernatant transferred into the

same volumetric flask. The latter step was repeated for the third time combining the clear supernatant into the same volumetric flask. The volume was made up to mark with 1.0 M KCl.

Titration for H and Al (Titrimetric method)

Fifty millilitres of the KCl extract was pipetted into 250 ml Erlenmeyer flask, and approximately 100 ml of distilled water added. Five drops of phenolphthalein indicator was added and the solution was titrated with 0.05M NaOH to a permanent pink end point with alternate stirring and standing. A few more drops of indicator were added to replace that adsorbed by the precipitate to Al (OH)₃ when needed. The amount of base used was equivalent to the total amount of acidity (H⁺ and Al³⁺) in the aliquot taken to the same flask. One drop of 0.05 M HCl was added to bring the solution back to the colourless condition followed by the addition of 10 ml NaF solution to change the colour of solution to pink. The solution was titrated with 0.05 M HCl until the pink colour of the solution disappeared. This was done while the solution was being stirred constantly. Two drops of indicator were added for the appearance of colour, 0.05 M HCl was continually added until the colour disappeared and did not return within 2 minutes. The milliequivalent of acid used is equal to the amount of exchangeable Al. This value was subtracted from the milliequivalent of total acidity from the base titration to obtain milliequivalent of exchangeable H. The exchangeable H and Al were then expressed in cmol_c kg⁻¹ of soil (Mclean, 1965).

$$\text{Ex A} = \text{Ex H}^+ + \text{Ex Al}^{3+} \dots\dots\dots (10.0)$$

Where,

Ex A= Exchangeable acidity

Ex H⁺ = Exchangeable hydrogen ion concentration

Ex Al³⁺ = Exchangeable aluminium ion concentration

$$\text{Ex A (cmol}_e \text{ kg}^{-2}) = \left(\frac{\text{NaOH}_{\text{dif}}}{W} \right) \times \left(\frac{0.1 \text{ mmol H}^+}{\text{ml NaOH}} \right) \times \left(\frac{0.1 \text{ cmol H}^+}{\text{mmol H}^+} \right) \times 10^3 \text{ g kg}^{-1} \text{ soil}$$

$$\text{cmol}_e \text{ Al}^{3+} \text{ kg}^{-1} = \left(\frac{\text{HCl}_{\text{sample}}}{W} \right) \times \left(\frac{0.1 \text{ mmol Al}^{3+}}{\text{ml HCl}} \right) \times \left(\frac{0.1 \text{ cmol Al}^{3+}}{\text{mmol Al}^{3+}} \right) \times 10^3 \text{ g kg}^{-1} \text{ soil}$$

Where, NaOH_{dif} = ml of NaOH added to sample filtrate less ml of NaOH added to blank solution

W = weight of dry soil

HCl_{sample} = volume of HCl added to sample (mL)

Therefore:

$$\text{Exchangeable acidity} = \text{Exchangeable H}^+ + \text{Exchangeable Al}^{3+}$$

Determination of exchangeable bases (potassium, sodium, calcium, magnesium)

Analyses of the exchangeable bases (Ca²⁺, Mg²⁺, K⁺ and Na⁺) were done by the method described by Anderson and Ingram (1993).

Thirty milliliters of 1M NH₄OAC was added to 5 g of sample and shaken with a mechanical shaker for 2 hours. The clear supernatant of the mixture was carefully decanted into a 100 ml volumetric flask after it was centrifuged at 2000 rpm for 10 min. Another 30 ml of NH₄OAC solution was added and shaken for 30 minutes prior to centrifuging and the supernatant transferred into the same volumetric flask. The latter step was repeated and the supernatant transferred into the same volumetric flask and made up to the mark with the NH₄OAC solution. Potassium and sodium were determined on a flame photometer (Jenway PFP 7) model where calibration graphs of

concentrations against photometer readings were plotted for K and Na. Calcium and magnesium were determined by titration method.

Calculations for Potassium and Sodium

Exchangeable Potassium in $\text{cmol}_c \text{ kg}^{-1}$ is given by:

$$\text{Exchangeable K} = \frac{C \times 10}{\text{wt} \times 39.1} \dots \dots \dots (11.0)$$

Exchangeable Sodium in $\text{cmol}_c \text{ kg}^{-1}$ is given by:

$$\text{Exchangeable Na} = \frac{C \times 10}{\text{wt} \times 22.99} \dots \dots \dots (12.0)$$

Where C = concentration from the graph

wt = weight of the soil sample

Determination of calcium (Ca) and magnesium (Mg)

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

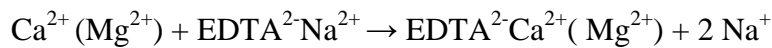
Calcium plus magnesium by titration

An aliquot of 25 ml of the extract was transferred into a 250 ml conical flask and diluted to 150 ml with distilled water. Ten drops each of KCN, NH_2OH , HCN and triethanolamine, and 10 % NaOH were added to it to raise the pH to 12 or slightly higher. Five drops of calcon indicator was added to the mixture. The solution was titrated with 0.005 M EDTA from red to blue end point.

Calcium by titration

The same procedure for determining $\sum (\text{Ca}^{2+}, \text{Mg}^{2+})$ was followed but the indicator used was murexide indicator.

Calculations for Calcium and Magnesium



$$(\text{Ca}^{2+} + \text{Mg}^{2+}) \text{cmol}_c \text{ kg}^{-1} \text{ soil} = \frac{4 \times T}{W_t} \dots \dots \dots (13.0)$$

$$\text{Ca}^{2+} \text{ cmol}_c \text{ kg}^{-1} \text{ soil} = \frac{4 \times T}{W_t} \dots \dots \dots (14.0)$$

Where,

T= titre value

Wt= weight of soil sample

The difference in the titre values between $\sum (\text{Ca}^{2+}, \text{Mg}^{2+})$ and Ca^{2+} alone was used for calculating exchangeable magnesium.

Effective cation exchange capacity (ECEC)

Effective cation exchange capacity in soil was determined by the sum of exchangeable bases (calcium, magnesium, sodium and potassium) and exchangeable acidity (aluminium and hydrogen) expressed in $\text{cmol}_c \text{ kg}^{-1}$. (Anderson and Ingram, 1993).

Determination of total nitrogen (N)

Total nitrogen was determined by the micro-Kjeldahl method (Rowell, 1994). Half a gram of soil sample was weighed into a digestion flask. One-tenth of a gram of catalyst and 3 ml of conc. H_2SO_4 were added. The flask with the contents was gently heated on a block digest and digested for 2 hrs. The digest was then allowed to cool down and diluted to 100 ml with distilled water. A steam distillation apparatus was set up. The steam was passed through the distillation apparatus for about 20 minutes. A 100 ml conical flask containing 5 ml of boric acid indicator solution was placed under the condenser of the distillation apparatus. An aliquot (20 ml) of the sample digest

was transferred to the reaction chamber through the trap funnel. Ten milliliters of alkali mixture was added and 40 ml of distillate was collected. The distillate was titrated against 0.007 M HCl from green to the initial colour of the methyl red indicator. Percent total nitrogen was calculated with the formula below:

$$\% N = \frac{100 \times (T - B) \times M \times 0.014 \times 100}{W \times A} \dots \dots \dots (15.0)$$

T = Titre for sample, cm³

B = Titre for blank, cm³

M = Molarity of the HCl, mol dm³

W = Weight of the soil sample, g

A = Aliquot of the sample digest

100 = Total volume of digest and

0.014 = Milliequivalent weight of nitrogen

Determination of available phosphorous (P)

Available Phosphorus was determined by the Bray No. 1 method (Bray and Kurtz, 1945). One gram of soil sample was weighed into a 15 ml centrifuge tube and 10 ml of extracting solution was then added to each tube. The tube plus its content was shaken for 5 minutes and the content filtered through a Whatmann No. 42 filter paper. Two millilitres aliquot of the extract was pipetted into 25 ml volumetric flasks. Then 100 ml 5 µg P ml⁻¹ 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. Ten milliliters of distilled water was added to each flask. 4 ml of the reagent was then added and made or topped up to volume with

distilled water. Finally, the blue colour was then allowed to develop for 15 minutes and the absorbance was determined on a spectrophotometer (CECIL CE 1021/ 1000 SERIES) at 882 nm.

Calculation

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

$$P = \frac{C \times 12.5}{W_s} \dots \dots \dots (16.0)$$

Where C = concentration derived from the standard curve

W_s = weight of soil sample

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

Determination of Zinc (Zn), Iron (Fe), Copper (Cu) and Lead (Pb)

The universal extractant, diethylenetriamine pentaacetic acid (DTPA) was used for the extraction of the elements which included Zinc, Iron, Copper and Lead (FAO, 2008). Buck scientific Atomic Absorption Spectrophotometer was used for the estimation of the elements in the extract.

Procedure

Approximately 2 g of diethylene triamine pentaacetic acid (DTPA) and 1.47 g calcium chloride dihydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) were weighed into a beaker. The mixture was dissolved with deionized water and transferred to a 1 litre volumetric flask. To the mixture, 13.38 ml triethanolamine (TEA) was added and transferred with deionised water, and made up to about 900 ml with deionised water. Ten grammes of air-dried soil (2-mm) was weighed into a 125-ml Erlenmeyer flask. Twenty milliliters extraction solution was added and shaken for 2 hours on a reciprocal shaker. The suspension was filtered through a Whatman No. 42 filter paper. Zinc, Iron, Copper, and Lead were determined directly in the filtrate by an Atomic Absorption Spectrophotometer.

Standard solutions and optimum range for each element (Linear relationship on digital readout)

1. Zn standards – 0, 0.5, 1.2 and 3 ppm Zn in aqueous solution.
2. Cu standards – 0, 2, 10, 15 and 20 ppm Cu in aqueous solution.
3. Fe- 0, 1, 2, 3 and 5 ppm Fe in aqueous solution.
4. Pb- 0, 1, 2, 3 and 5 ppm Pb in aqueous solution.

The concentration readout was standardized by using the standard solutions of the element tested. The concentration of the element in samples solution were read and recorded.

For extractable micronutrient cations in soil:

$$\text{Fe, Cu, Zn or Pb (ppm)} = (\text{ppm in extract}) \times \frac{A}{Wt} \dots \dots \dots (17.0)$$

Where: A = Total volume of the extract (ml)

Wt = Weight of air-dried soil (g)

Soil Texture

Soil particle size distribution was determined using the pipette method (Rowell, 1994). Ten grams of soil was placed in a 500 ml beaker. The organic matter residue in the soil was destroyed by adding 10 ml of hydrogen peroxide to the soil followed by few drops of amyl alcohol to reduce frothing in samples with high amount of organic matter and was allowed to stand until frothing ceased. After several swirling, another 10 ml of hydrogen peroxide was added. When there was no further reaction the beaker was gently heated and its content stirred to break the froth. Finally, the temperature was raised to boiling to complete the destruction of the organic matter. The beaker was allowed to cool. The content of the beaker was completely transferred into a

bottle to just about half full for effective shaking. Ten millilitres of dispersing agent made up of sodium hexametaphosphate and anhydrous sodium carbonate was added to the suspension and shaken overnight on a mechanical shaker. The suspensions were transferred into 500 ml cylinders and made up to the 500 ml mark employing the use of the wash bottle to ensure that all the soil particles had been transferred. The cylinders were allowed to stand on a laboratory bench to effect sedimentation of particles for about 30 minutes.

The cylinder with content was placed under a pipette assembly. **a.** After 40 seconds, the tip of pipette was inserted a few centimetres into the suspension and 25 ml of the suspension was pipetted and transferred into a 50 ml beaker of known weight to be dried overnight in an oven. **b.** After 5 hours the latter process was repeated. The remaining suspension was passed through a 0.3 mm sieve, which was placed above a 500 ml sedimentation cylinder with a stand and a clamp. **c.** 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 over night in an oven at 105 °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.

Calculation of Particle Size

Pipetted volume of silt + clay (a) = 25 ml

Pipetted volume of clay only (b) = 25 ml

Total volume of suspension = 500 ml

Xg = weight of silt + clay in 25 ml pipetted suspension

Yg = weight of clay in the 25 ml pipetted suspension

$W_{(a1)}$ = Empty weight of beaker containing silt and clay suspension.

$W_{(asc)}$ = Weight of beaker plus silt and clay contents in suspension after drying.

$W_{(b1)}$ = Empty weight of beaker containing clay suspension.

$W_{(bsc)}$ = Weight of beaker plus clay contents in suspension after drying

$W_{(c1)}$ = Empty weight of beaker containing sand.

$W_{(cs)}$ = Weight of beaker plus sand contents after drying

(a) $W_{(a1)} - W_{(asc)} = Xg$ (18.0)

Then in 500 ml, wt. of silt + clay = $500 \times Xg / 25$ -----(18.1)

(b) $W_{(b1)} - W_{(bsc)} = Yg$(18.2)

Then in 500 ml, wt. of clay = $500 \times Yg / 25$ -----(18.3)

(18.1) - (18.3) = wt. of silt **(10.4)**

Therefore % Silt = $(18.4) \times 100 / \text{wt. of soil}$

% Clay = $(18.3) \times 100 / \text{wt. of soil}$

(c) $W_{(c1)} - W_{(cs)} = \text{wt. of sand}$(18.5)

% Sand = $(18.5) \times 100 / \text{wt. of soil}$

Gravimetric Water Content (GWC)

The moisture content was determined as described by (Rowell, 1994). Soil samples were air-dried for 5 days in order to bring all the samples under a uniform condition prior to the determination. Samples were thoroughly mixed in the zip-locked bags to ensure uniform distribution of the sample. Approximately 10 g of the air-dried soils were placed into beakers of known weights (A) and the weights (B) of soil and beaker recorded. The beakers with their contents were oven-dried at 105 °C for about 24 hours. Subsequently, the beakers were cooled to room temperature and weighed. This exercise was repeated until constant weights (C) were obtained.

Calculation of Gravimetric water content

Gravimetric water content in % is defined as:

$$\% \text{ GWC} = \frac{M_w}{M_s} \times 100 \dots\dots\dots (19.0)$$

Where,

M_s = the mass of water (g)

M_b = mass of dry soil (g)

$M_w = C - B$

$M_b = C - A$

A = mass of beaker

B = mass of beaker plus soil before drying

C = mass of beaker and soil after drying

Bulk density (B D)

Bulk density- ASTM D 2937-83: The Standard Test Method for Density of Soil in Place as described by Anderson and Ingram (1993) was used. Samples were taken from the 0-10 cm and 10-20 cm layers by the use of the core samplers. The volume (V) and weight (W1) of the core samples were recorded. The compacted soils in the samplers were oven dried for 2 days after which they were re-weighed (W2). The dry bulk densities of the samples were calculated as follows: Bulk density (B D) in g cm^{-3} is given by:

$$\text{B.D} = \frac{(W_2 - W_1)}{V} \dots\dots\dots (20.0)$$

Where,

V= the volume of core sample (volume of the cylindrical core sampler)

$$V = \pi d^2 h / 4$$

$\pi = \text{pi (constant)}$

d and h = diameter and length of core sampler respectively

Particle density (P D)

Twenty-five grams (M(ds)) of oven-dried soil was transferred to a 250 ml beaker of known weight (M(b)) and the beaker and its content reweighed (M(b+ds)). About 50 cm³ of water was added and boiled gently to disperse the soil and expel the air. The suspension was cooled under running water. The suspension was then poured into a 250 ml (V(f)) volumetric flask of known weight (M(f)). The wash bottle was constantly washed in the latter stage to ensure that all the soil particles had been transferred. It was then made up to the mark after which the flask plus suspension were weighed (M(f+s)) (Anderson and Ingram, 1989).

Calculation of Particle Density

Particle density (*P. D*) in g cm⁻³ is given by:

$$\text{Particle density (P.D)} = \frac{M(ds)}{V(pf)} \dots\dots\dots (21.0)$$

Where,

M(ds) = Mass of dry soil

M(b) = Mass of beaker

M(b+ds) = Mass of beaker + dry soil

V(f) = Volume of the flask

M(f) = Mass of flask

M(f+s) = Mass of flask + suspension

M(s) = Mass of suspension

V(p) = Volume of particles

V(ws) = Volume of water in suspension

M(wf) = Mass of water in flask

V(pf) = The volume of particles in flask

$$M(ds) = M(b + ds) - M(b)$$

$$M(s) = M(f + s) - M(f)$$

$$M(wf) = M(s) - M(ds)$$

$$\text{Density of H}_2\text{O} = 1 \text{ g cm}^{-3} \Rightarrow M(wf) \times 1 = \text{volume of H}_2\text{O}$$

Therefore,

$$V(ws) = M(s) - M(ds)$$

$$V(pf) = V(f) - V(ws)$$

Porosity (Po)

The porosity of samples was determined by using the equation below:

(Globe®, 2002).

$$\text{Porosity \%} = \left(1 - \frac{BD}{PD}\right) \times 100 \dots \dots \dots (22.0)$$

Where,

BD= Bulk density

PD= Particle density

Data Analyses/ Softwares used

Classical analyses performed on the raw data included simple descriptive statistical analyses such as means, coefficient of variation and skewness using GENSTAT (Discovery edition 3) and Microsoft Excel 2007 statistical packages. Pearson's correlation among the variables were carried out using SPSS and spatial patterns were determined using GENSTAT statistical software.

The semi-variogram was computed using the equation below:

$$\gamma(h) = \frac{1}{2N(h)} [Z(X_i)] - Z[(X_i + h)]^2 \dots \dots \dots (23.0)$$

Where, $Z(X)$ and $Z(X + h)$ are the values of a random function representing the soil property of interest, Z , at places X , and $(X + h)$ separated by the vector h , known as the lag. $N(h)$ represents the number of pairs of observation (Webster, 1985).

In addition the Arc- GIS (Version 9.3) mapping software was employed

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents results and discusses the same. It covers the following: descriptive statistics of soil variables, correlation amongst soil variables and finally, the patterns of variations in soil properties.

Results

Classical approach

From Tables 1 and 2, mean values of 48.7% and 32.9 % were recorded sand for top and subsoils respectively. Both top and subsoil showed a common range of 5.0 - 71.0 % and coefficient of variations (CV) of 27.9 % and 51.6 % respectively. Skewness was found to be -1.10 and 0.15 for top and subsoils respectively

For top and sub soils, mean silt values recorded were 19.4 % and 34.9 % respectively against their respective ranges of 8.0 – 75 % and 8.0 – 65 %. CVs and skewness determined were 60.6 % and 43.0 % and 1.7 and 0.39 for top and subsoils respectively.

The mean values of clay recorded were 32.1 % and 32.5 % with ranges of 2.0 - 61.0 % and 8.0 – 70.0 %. CVs of 23.6 % and 25.4 % were recorded for top and subsoils respectively. Skewness of -1.15 and 0.63 were also determined.

For surface and sub soils, mean bulk density values recorded were 1.4 g cm⁻³ and 1.7 g cm⁻³ against their respective ranges of 1.3 – 1.7 g cm⁻³ and 1.5 – 2.2g cm⁻³ with CVs of 5.7 % and 8.5 % respectively. Skewness of 0.902 and 0.86 for top and subsoils respectively were determined.

The mean porosity was 42.0 % for topsoils against that of 39.6 % for subsoils. Ranges recorded for top and subsoils were 24 – 46 % and 8 – 42 % respectively. CVs of 8.8 % and 21.5 % and skewness of -1.54 and 0.30 were determined for top and subsoils respectively.

Mean soil gravimetric moisture content levels for top and subsoil layers was 15.8 % and 16.2 % respectively with their respective ranges of 9 - 23.1 % and 9.2 – 23.1 %. From the results, CVs of 20.6 % and 15.5 % were determined for top and subsoil layers respectively. Skewness recorded for top and subsoils were -0.051 and 0.46 respectively.

The mean pH of top and subsoils recorded were 5.5 and 5.4 respectively. The range values were between 4.3 - 6.7 for topsoil and 4.1 – 6.7 for subsoil. CVs of 11.9 % and 12.3 % were recorded for top and subsoils respectively. Skewness determined for top and subsoils were 0.060 and 0.040 respectively.

The mean values determined for organic carbon were 1.2 % and 1.1 % for top and sub soils respectively. Range values of 0.13 – 2.95 % and 0.01 – 2.93 % and CVs of 36.3 % and 32.6 % were recorded for top and subsoils respectively. Skewness for top soils was 0.96 and 0.88 for sub soils.

For total nitrogen, mean values of 0.11 % and 0.10 % were determined for top and sub soils respectively. Range values were found to be 0.01 – 0.19 % and 0.01- 0.47 % respectively for top and subsoils. Topsoils yielded a CV of 29.6 % against a 33.3 % recorded for subsoils. Skewness of 0.27 and 1.07 were determined for top and subsoils respectively.

Mean values of $9.0 \mu\text{g g}^{-1}$ and $8.8 \mu\text{g g}^{-1}$ were recorded for available phosphorous in top and sub soil layers with determined range values of $0.67 - 17.97 \mu\text{g g}^{-1}$ and $0.47 - 16.87 \mu\text{g g}^{-1}$ respectively. A common CV value of 6.8 % was recorded for both top and subsoils and skewness for top soils was -0.03 and -0.08 for subsoils.

For exchangeable potassium, mean values of $0.89 \text{ cmol}_c \text{ kg}^{-1}$ and $0.9 \text{ cmol}_c \text{ kg}^{-1}$ were recorded for top and sub soils respectively. A range value of $0.02- 0.72 \text{ cmol}_c \text{ kg}^{-1}$ was determined for topsoils as against that of $0.04 - 0.74 \text{ cmol}_c \text{ kg}^{-1}$ for subsoils. CVs recorded for top and subsoils were 40.5 % and 37.5 % with skewness for top and subsoils recording 1.04 and 1.07 respectively.

Mean values determined for Exchangeable sodium were $0.26 \text{ cmol}_c \text{ kg}^{-1}$ and $0.27 \text{ cmol}_c \text{ kg}^{-1}$ with ranges of $0.02 - 0.33 \text{ cmol}_c \text{ kg}^{-1}$ and $0.03- 0.34$ for top and subsoil layers respectively. Recorded CVs for top and subsoils were 25.5 % and 24.5 % with skewness of -1.48 and 1.07 for top and subsoils respectively.

The mean values for exchangeable calcium were $3.56 \text{ cmol}_c \text{ kg}^{-1}$ and $3.59 \text{ cmol}_c \text{ kg}^{-1}$ against ranges $0.54 - 7.96 \text{ cmol}_c \text{ kg}^{-1}$ and $0.57 - 7.99 \text{ cmol}_c \text{ kg}^{-1}$ for top and subsoils respectively. The CVs recorded for top and subsoils

were 45.6 % and 45.3 % respectively. Skewness for both top and subsoils was 0.27.

For exchangeable magnesium, mean values of 0.89 $\text{cmol}_c \text{kg}^{-1}$ and 0.9 $\text{cmol}_c \text{kg}^{-1}$ were recorded for top and sub soils respectively. Ranges determined were 0.01 – 2.24 $\text{cmol}_c \text{kg}^{-1}$ and 0.02- 2.25 $\text{cmol}_c \text{kg}^{-1}$ respectively for top and subsoils. CVs were 47.3 % and 46.8 % for top and subsoils respectively. A common skewness value of 0.92 was recorded for both soil layers.

Mean values recorded exchangeable acidity were 5.4 $\text{cmol}_c \text{kg}^{-1}$ and 5.42 $\text{cmol}_c \text{kg}^{-1}$ against ranges of 5.03- 7.56 $\text{cmol}_c \text{kg}^{-1}$ and 5.05- 7.58 $\text{cmol}_c \text{kg}^{-1}$ for top and subsoils respectively. CVs recorded for top and subsoils were 11.1 % and 11.19 % respectively. Skewness recorded for both soil layers was 1.88.

For effective cation exchange capacity, the mean values of 10.32 and 10.41 $\text{cmol}_c \text{kg}^{-1}$ alongside range values of 6.62- 15.93 $\text{cmol}_c \text{kg}^{-1}$ and 6.71- 16.02 $\text{cmol}_c \text{kg}^{-1}$ for top and subsoils respectively were determined. Recorded CVs for top soil was 15.6 % and 15.5 % for subsoils with a skewness of 0.22 for both soil layers.

Determined mean values for base saturation were 76.3 % and 76.4 % against range values of 33.33- 88.98 % and 34.23- 89.58 % for top and subsoils respectively. CV for top and subsoils were 15.3 % for and 15.10 % with skewness of -1.52 and -1.51 respectively.

Mean levels of iron recorded were $13.1 \mu\text{g g}^{-1}$ and $12.8 \mu\text{g g}^{-1}$ for top and sub soils respectively with respective range values of $0.3 \mu\text{g g}^{-1}$ - $43.1 \mu\text{g g}^{-1}$ and $0.13 \mu\text{g g}^{-1}$ - $42.98 \mu\text{g g}^{-1}$. CVs recorded for top and subsoils were 60.3 % and 61.4 % with skewness of 0.64 and 0.65 respectively.

The mean levels of zinc were found to be $0.69 \mu\text{g g}^{-1}$ and $0.64 \mu\text{g g}^{-1}$ for top and sub soils respectively. For topsoils range values were 0.10-2.10 $\mu\text{g g}^{-1}$ whilst for subsoils values were 0.01-2.02 $\mu\text{g g}^{-1}$. CVs of 77.2 % and 79.9 % and skewness of 0.23 and 0.27 were recorded for topsoils and subsoils respectively.

For copper, mean values recorded were $0.36 \mu\text{g g}^{-1}$ and $0.37 \mu\text{g g}^{-1}$ and range values of 0.01 - 1.78 and 0.01 - 7.0 for top and subsoils respectively. CVs and skewness were found to be 96.8 % and 116.7 % and, 1.34 and 5.9 for top and for subsoils respectively.

The mean values of lead for both soil layers was 0.04 with topsoils recording a range of 0.01- 0.50 whilst subsoils recorded a range of 0.01- 0.42. CVs and skewness determined were 139.9 % and 130.8 % and 3.37 and 2.47 for top and subsoils respectively.

Table 1: Descriptive statistics of soil variables studied (Top soil)

Variable		Range	Mean	CV (%)	Skewness
Sand	(%)	5.0 - 71.0	48.7	27.9	-1.10
Silt	(%)	8.0 - 75.0	19.4	60.6	1.70
Clay	(%)	2.0 - 61.0	32.1	23.6	- 1.15
B D	(g cm ⁻³)	1.3- 1.7	1.4	5.7	0.902
Porosity	(%)	24.0 - 46.0	39.6	8.8	-1.54
GWC	(%)	9.0 – 23.1	15.81	20.6	-0.051
pH	(pH unit)	4.3 - 6.7	5.5	11.9	0.060
Organic C	(%)	0.13- 2.95	1.2	36.3	0.96
Nitrogen	(%)	0.01 – 0.19	0.11	29.6	-0.27
Av. P	(µg g ⁻¹)	0.67 – 17.97	9.00	61.8	-0.03
Ex. K	(cmol _c kg ⁻¹)	0.02 - 0.72	0.22	40.5	1.04
Ex. Na	(cmol _c kg ⁻¹)	0.02 - 0.33	0.26	25.5	-1.48
Ex. Ca	(cmol _c kg ⁻¹)	0.54 - 7.96	3.56	45.6	0.27
Ex. Mg	(cmol _c kg ⁻¹)	0.01 - 2.24	0.89	47.3	0.92
Ex. Acidity	(cmol _c kg ⁻¹)	5.03 - 7.56	5.40	11.1	1.88

CV = Coefficient of variation. ECEC= Effective Cation Exchange Capacity
GWC = Gravimetric Water Content. Av. = Available. Ex. = Exchangeable
BD= Bulk density

Table 1 continued

Variable		Range	Mean	CV (%)	Skewness
ECEC	($\text{cmol}_c \text{ kg}^{-1}$)	6.62 - 15.93	10.32	15.6	0.22
B S	(%)	17.37 – 66.27	46.42	22.0	-0.63
Fe	($\mu\text{g g}^{-1}$)	0.3 - 43.1	13.10	60.3	0.64
Zn	($\mu\text{g g}^{-1}$)	0.10 - 2.10	0.69	77.2	0.23
Cu	($\mu\text{g g}^{-1}$)	0.01 - 1.78	0.36	96.8	1.34
Pb	($\mu\text{g g}^{-1}$)	0.01- 0.50	0.04	139.9	3.37

CV = Coefficient of variation. ECEC= Effective Cation Exchange Capacity
BS = Base Saturation.

Table 2: Descriptive statistics of soil variables studied (Sub soil)

Variable		Range	Mean	CV (%)	Skewness
Sand	(%)	5.0 – 71.0	32.9	51.6	0.15
Silt	(%)	8.0 – 65.0	34.9	43.0	0.39
Clay	(%)	8.0 – 70.0	32.5	25.4	- 0.63
B D	(g cm^{-3})	1.5 - 2.2	1.7	8.5	0.86
Porosity	(%)	8.0 - 42.0	19.9	21.5	0.30
GWC	(%)	9.2 – 23.1	16.2	15.5	0.46

CV = Coefficient of variation. GWC = Gravimetric Water Content.

Table 2 continued.

Variable		Range	Mean	CV (%)	Skewness
pH	(pH unit)	4.1 - 6.7	5.4	12.3	0.04
Organic C	(%)	0.01 - 2.93	1.1	32.6	0.88
Nitrogen	(%)	0.01 - 0.47	0.1	33.3	1.07
Av. P	($\mu\text{g g}^{-1}$)	0.47 - 16.87	8.8	61.8	-0.08
Ex. K	($\text{cmol}_c \text{kg}^{-1}$)	0.04 - 0.74	0.24	37.5	1.07
Ex. Na	($\text{cmol}_c \text{kg}^{-1}$)	0.03 - 0.34	0.27	24.5	-1.48
Ex. Ca	($\text{cmol}_c \text{kg}^{-1}$)	0.57 - 7.99	3.59	45.3	0.27
Ex. Mg	($\text{cmol}_c \text{kg}^{-1}$)	0.02 - 2.25	0.90	46.8	0.92
Ex. Acidity	($\text{cmol}_c \text{kg}^{-1}$)	5.05 - 7.58	5.42	11.2	1.88
ECEC	($\text{cmol}_c \text{kg}^{-1}$)	6.71 - 16.02	10.4	15.5	0.22
B S	(%)	18.01- 66.34	46.7	21.63	-0.63
Fe	($\mu\text{g g}^{-1}$)	0.13 - 42.98	12.8	61.4	0.65
Zn	($\mu\text{g g}^{-1}$)	0.01 - 2.02	0.64	79.9	0.27
Cu	($\mu\text{g g}^{-1}$)	0.01 - 7.0	0.37	116.7	5.9
Pb	($\mu\text{g g}^{-1}$)	0.01 - 0.42	0.04	130.8	2.47

CV = Coefficient of variation. ECEC= Effective Cation Exchange Capacity
Av. = Available. Ex. = Exchangeable

Tables 3 and 4 show correlation coefficients between the chemical and physical properties of the soils studied displayed in a triangular matrix.

According to Tables 3 and 4, soil pH correlated significantly with all other soil properties at $p < 0.01$. Significantly negative correlations were observed between subsoil pH and clay ($r = -0.68$; $p < 0.01$) as well as pH and exchangeable acidity ($r = -0.69, -0.60$; $p < 0.01$) respectively for top and subsoils. Significantly positive correlations existed between subsoil pH and sand ($r = 0.59$; $p < 0.01$). Calcium and effective cation exchange capacity showed a positive correlation ($r = 0.91$; $p < 0.01$). Similarly, a negative correlation also occurred between sand and silt ($r = -0.82, 0.87$; $p < 0.01$) for top and sub soils respectively. Negative correlations also occurred between exchangeable acidity and exchangeable sodium ($r = -0.82$; $p < 0.01$), exchangeable acidity and base saturation ($r = -0.82$; $p < 0.01$) for both top and sub soils. Organic carbon showed a positive correlation with nitrogen. Sub soil nitrogen positively correlated with organic carbon ($r = 0.78$; $p < 0.01$) whilst base saturation and exchangeable sodium ($r = 0.72, 0.71$; $p < 0.01$) and base saturation and exchangeable calcium ($r = 0.72, 0.73$; $p < 0.01$) also showed positive associations for top and subsoils respectively. Negative correlations were observed for bulk density and Porosity ($r = -0.65, -0.54$; $p < 0.01$) for both soil depths. A negatively correlation was observed for exchangeable acidity and available phosphorus ($r = -0.53$; $p < 0.01$ for both soil layers. Other significantly negative correlations were observed between top soils clay and sand ($r = -0.5$; $p < 0.01$) as well as sub soils available phosphorus and bulk density ($r = -0.65$; $p < 0.01$) and base saturation and lead ($r = -0.50$; $p < 0.01$). Significantly positive correlations existed between top soil nitrogen and

organic carbon ($r= 0.64$; $p<0.01$) as well as topsoil exchangeable acidity and lead ($r= 0.50$; $p<0.01$), subsoil available phosphorus and porosity ($r= 0.51$; $p<0.01$) and subsoil exchangeable acidity and bulk density ($r= 0.52$; $p<0.01$). Soil organic carbon showed significant negative correlations with clay ($r= -0.04, -0.13$; $p<0.01$) as well as silt ($r= -0.13, -0.14$; $p<0.01$) for top and subsoils respectively.

Table 3: Correlation coefficients among top soils variables studied

	S	Si	Cl	BD	Po	GWC	pH	OC	N	Av. P	Ex. K	Ex. Na	Ex. Ca	Ex.Mg	Ex.Ac	ECEC	BS	Fe	Zn	Cu	Pb
S	-	-0.82**	-0.50**	-0.14**	0.32**	0.15**	0.30**	0.13**	0.14**	0.38**	0.10**	0.27**	0.21**	0.01	-0.27**	0.13**	0.25**	-0.18**	0.04	0.16**	-0.19**
Si	-	-	-0.08*	0.12**	-0.21**	-0.13**	-0.10**	-0.13**	-0.10**	-0.30**	-0.03	-0.20**	-0.11**	0.02	0.12**	-0.08*	-0.12**	0.03	-0.08*	-0.01	0.06
Cl	-	-	-	0.07*	-0.23**	-0.06	-0.37**	-0.04	-0.11**	-0.21**	-0.14**	-0.17**	-0.19**	-0.03	0.29**	-0.11**	-0.26**	0.26**	0.05	-0.28**	0.24**
BD	-	-	-	-	-0.65**	-0.15**	-0.38**	-0.16**	-0.13**	-0.47**	-0.12**	-0.36**	-0.18**	0.10**	0.38**	-0.04	-0.24**	0.20**	0.003	-0.22**	0.33**
Po	-	-	-	-	-	0.23**	0.33**	0.13**	0.14**	0.37**	0.09*	0.24**	0.22**	-0.12**	-0.23**	0.12**	0.23**	-0.13**	-0.14**	0.24**	-0.22**
GWC	-	-	-	-	-	-	0.08*	0.17**	0.19**	0.34**	0.16**	-0.01	0.04	-0.09**	0.05	0.05	-0.004	0.05	-0.20**	0.11**	0.05
pH	-	-	-	-	-	-	-	0.12**	0.19**	0.44**	0.26**	0.71**	0.44**	-0.17**	-0.69**	0.19**	0.55**	-0.42**	-0.27**	0.34**	-0.41**
OC	-	-	-	-	-	-	-	-	0.64**	0.41**	0.12**	0.17**	0.02	-0.06	-0.23**	-0.07	0.07	-0.08*	0.06	0.02	-0.21**
N	-	-	-	-	-	-	-	-	-	0.30**	0.14**	0.11**	0.08*	-0.14**	-0.15**	0.002	0.09*	-0.13**	-0.15**	0.07	-0.12**
Av. P	-	-	-	-	-	-	-	-	-	-	0.18**	0.47**	0.23**	-0.02	-0.53**	0.06	0.34**	-0.23**	0.10**	0.08*	-0.28**
Ex. K	-	-	-	-	-	-	-	-	-	-	-	0.09*	0.11**	-0.10**	-0.11**	0.10**	0.14**	-0.14**	-0.19**	0.18**	-0.11**
Ex.Na	-	-	-	-	-	-	-	-	-	-	-	-	0.29**	-0.01	-0.82**	0.03	0.50**	-0.28**	0.17**	0.07	-0.43**
Ex. Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-0.30**	0.92**	0.92**	-0.17**	-0.13**	0.18**	-0.23**
Ex.Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.04	0.25**	0.22**	0.03	0.25**	-0.11**	0.04
Ex.Ac	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-0.54**	0.34**	-0.25**	-0.09*	0.50**
ECEC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.81**	-0.05	-0.16**	0.13**	-0.06
BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.32**	0.15**	0.15**	-0.46**
Fe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08*	-0.26**	0.16**
Zn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.22**	-0.16**
Cu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.12**

S = Sand Si = Silt Cl= Clay BD = Bulk Density Po = Porosity GWC= Gravimetric Water Content OC= Organic Carbon N= Nitrogen Ac= Acidity
 Av = Available Ex= Exchangeable**. Significantly different from zero at 99%.*, Significantly different from zero at 95%. N=755

Table 4: Correlation coefficients among sub soils variables studied

	S	Si	Cl	BD	Po	GWC	pH	OC	N	Av.P	Ex.K	Ex.Na	Ex.Ca	Ex.Mg	Ex.Ac	ECEC	BS	Fe	Zn	Cu	Pb
S	-	-0.87**	-0.44**	-0.23**	0.03	0.13**	0.59**	0.18**	0.13**	0.26**	0.21**	0.19**	0.27**	-0.23**	-0.20**	0.16**	0.25**	-0.24**	-0.24**	0.24**	-0.25**
Si	-	-	-0.03	0.13**	-0.02	-0.13**	-0.28**	-0.14**	-0.13**	-0.16**	-0.19**	0.04	-0.16**	0.20**	-0.02	-0.13**	-0.09*	0.15**	0.24**	-0.22**	0.10**
Cl	-	-	-	0.21**	-0.02	-0.02	-0.68**	-0.13**	-0.05	-0.25**	-0.10**	-0.45**	-0.25**	0.09*	0.44**	-0.09*	-0.32**	0.20**	0.05	-0.09*	0.33**
BD	-	-	-	-	-0.54**	-0.13**	-0.39**	-0.23**	-0.19**	-0.65**	-0.14**	-0.47**	-0.24**	0.02	0.52**	-0.07	-0.35**	0.27**	-0.03	-0.13**	0.40**
Po	-	-	-	-	-	0.10**	0.10**	0.23**	0.15**	0.51**	0.09*	0.23**	0.14**	0.02	-0.22**	0.08*	0.18**	-0.07*	-0.01	-0.04	-0.12**
GWC	-	-	-	-	-	-	0.14**	0.12**	0.07*	0.19**	0.07	-0.07	0.04	-0.16**	0.05	0.02	-0.01	-0.10**	-0.15**	0.14**	-0.03
pH	-	-	-	-	-	-	-	0.16**	0.11**	0.44**	0.22**	0.58**	0.40**	-0.11**	-0.60**	0.18**	0.49**	-0.38**	-0.16**	0.27**	-0.46**
OC	-	-	-	-	-	-	-	-	0.78**	0.35**	0.16**	0.13**	0.07	-0.11**	-0.17**	-0.01	0.08*	-0.10**	-0.03	0.04	-0.15**
N	-	-	-	-	-	-	-	-	-	0.24**	0.13**	0.07	0.05	-0.07	-0.12**	0.002	0.08**	-0.11**	-0.03	0.07	-0.17**
Av.P	-	-	-	-	-	-	-	-	-	-	0.17**	0.47**	0.23**	-0.01	-0.53**	0.06	0.35**	-0.24**	0.11**	0.08*	-0.33**
Ex.K	-	-	-	-	-	-	-	-	-	-	-	0.09*	0.11**	-0.10**	-0.10**	0.11**	0.15**	-0.14**	-0.17**	0.15**	-0.13**
Ex.Na	-	-	-	-	-	-	-	-	-	-	-	-	0.29**	-0.01	-0.82**	0.03	0.50**	-0.28**	0.17**	0.04	-0.47**
Ex.Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-0.30**	0.91**	0.92**	-0.17**	-0.13**	0.14**	-0.25**
Ex.Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.04	0.25**	-0.22**	0.02	0.25**	-0.09*	0.02
Ex.Ac	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-0.55**	0.33**	-0.25**	-0.08*	0.55**
ECEC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.80**	-0.06	-0.17**	0.09*	-0.07
BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.31**	0.15**	0.13**	-0.50**
Fe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-0.24**	0.18**
Zn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.19**	-0.17**
Cu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.12**

S = Sand Si = Silt Cl= Clay BD = Bulk Density Po = Porosity GWC= Gravimetric Water Content OC= Organic Carbon N= Nitrogen Ac= Acidity Av = Available Ex= Exchangeable**. Significantly different from zero at 99%.*. Significantly different from zero at 95%. N=755

Geostatistical approach

Figure 5 presents omni-directional variograms and fitted theoretical models of sand, silt, clay and bulk density for topsoils whilst Table 5 displays parameters of models fitted to various properties.

In Figure 5a variogram of sand fitted with a spherical model for top soils is portrayed. According to Table 5 a range of 9.6 m was observed for the variogram. It yielded a sill of 168 and nugget of 136.76. Nugget to Sill ratio Nugget to sill ratio was considered to 81.0.

Variogram for silt was fitted with a spherical model (Figure 5b). It showed a range of 5.7 m yielding a sill of 135 and nugget and 92.0. A Nugget to Sill ratio of 67.8 was determined (Table 5).

In Figure 5c variogram for clay was fitted with a pentaspherical model. According to Table 5, the variogram recorded a range of 5.2 m against a sill, and nugget of 54.17 and 35.93 respectively. A Nugget to Sill ratio value of 66.3 was obtained.

Figure 5d shows variograms for bulk density fitted with the bounded linear model. It recorded a range of 3.5 m, sill of 0.00474 and nugget of 0.00353. A Nugget to Sill ratio of 74.5 was determined (Table 5).

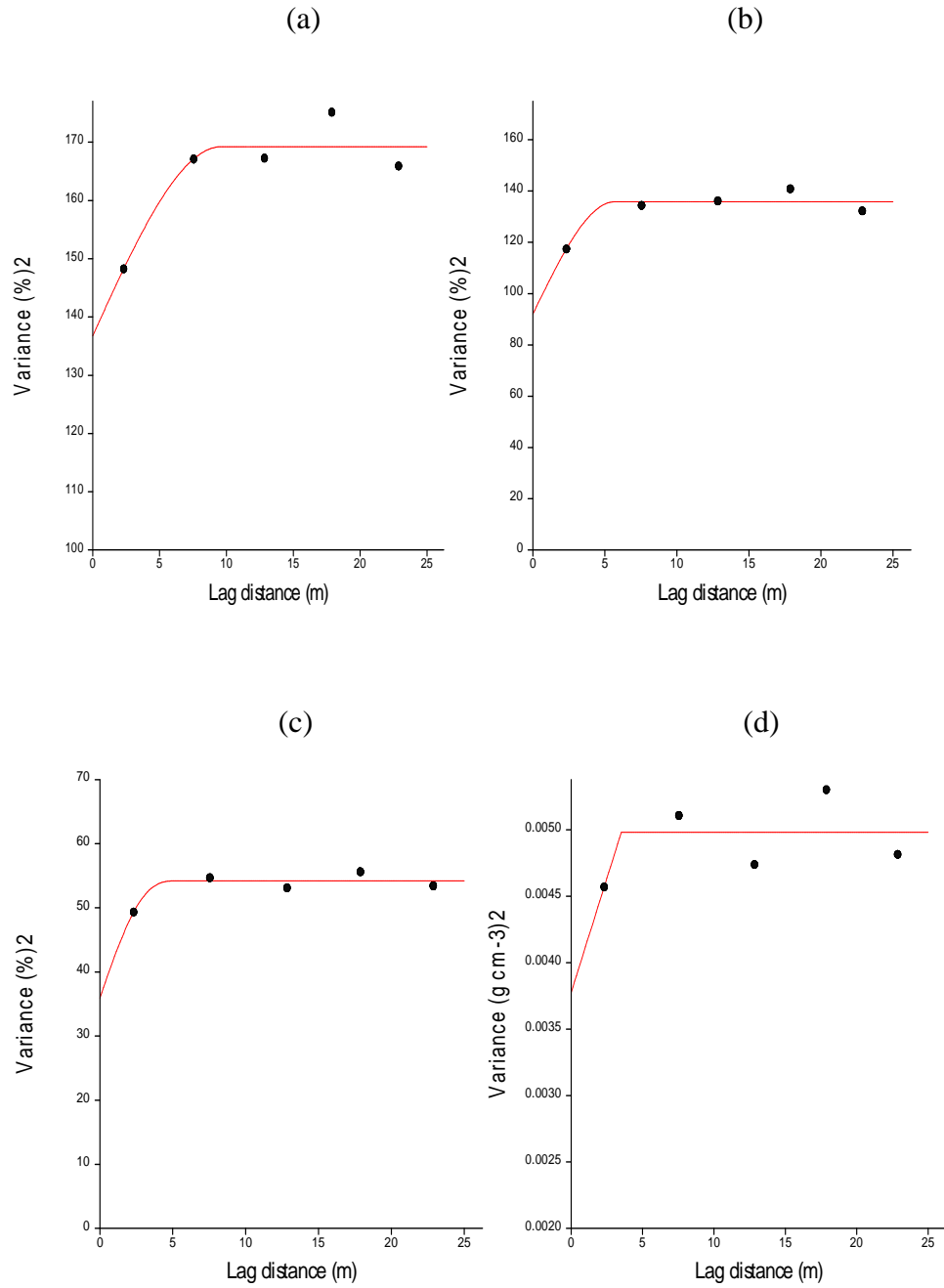


Figure 5: Omni-directional variograms (dots) and fitted theoretical functions (models): (a) Sand, (b) Silt, (c) Clay and (d) Bulk density for top soils

Table 5: Estimates of variograms of soil properties studied (Top soil)

VARIABLE	MODEL	RANGE (m)	SILL	NUGGET	N/S (%)
Sand	S	9.6	168.8	136.76	81.0
Silt	S	5.7	135.7	92.0	67.8
Clay	PS	5.2	54.17	35.93	66.3
B D	BL	3.5	0.00474	0.00353	74.5
Porosity	G	5.3	7.661	6.759	88.2
GWC	L	-	-	7.5311	-
pH	B	4.5	0.4682	0.3704	79.1
Organic C	E	11.2	0.1620	0.1412	87.2
Nitrogen	L	-	-	0.0009816	-
Av. P	E	2.8	19.0	13.4	70.5
Ex. K	L	-	-	0.0077778	-
Ex. Na	E	6.2	0.00490	0.00364	74.3
Ex. Ca	L	-	-	2.590	-
Ex. Mg	E	3.1	0.15958	0.13493	84.6
Ex. Acidity	E	7.3	0.3849	0.2698	70.1
ECEC	L	-	-	2.5411	-
B S	PS	24.5	103.91	95.67	92.1
Fe	S	5.2	65.23	56.0	85.9
Zn	E	5.9	0.2609	0.2221	85.1
Cu	S	4.0	0.0489	0.009	18.4
Pb	S	5.4	0.0024436	0.001437	58.8

S = Spherical G = Gaussian L = Linear PS = Pentaspherical BL = Bounded

Linear B = Bessel E = Exponential N/S = proportion of sill represented by the nugget.

Figure 6 presents omni-directional variograms and fitted theoretical models of porosity, GWC, pH and organic carbon for topsoils.

According to Figure 6a, variogram for sand was fitted with a gaussian model. It recorded a range of 5.3 m, sill of 7.661 and a nugget of 6.759. Estimated Nugget to Sill ratio for variogram was 88.2 % (Table 5).

Variogram for GWC was fitted with a linear model (Figure 6b). According to Table 5, the variogram yielded nugget of 7.5311.

In Figure 6c variogram for pH was fitted with a besse model. According to Table 5, a range of 4.5 m was observed for the variogram against sill and nugget values of 0.4682 and 0.3704 respectively. Nugget to Sill ratio was estimated to be 79.1 %.

As depicted by Figure 6d, variogram for organic carbon was fitted with the bounded linear model. Estimated range, sill and nugget for variogram were 11.2 m, 0.1620 and 0.1412 respectively. Estimated Nugget to Sill ratio was 87.2 %.

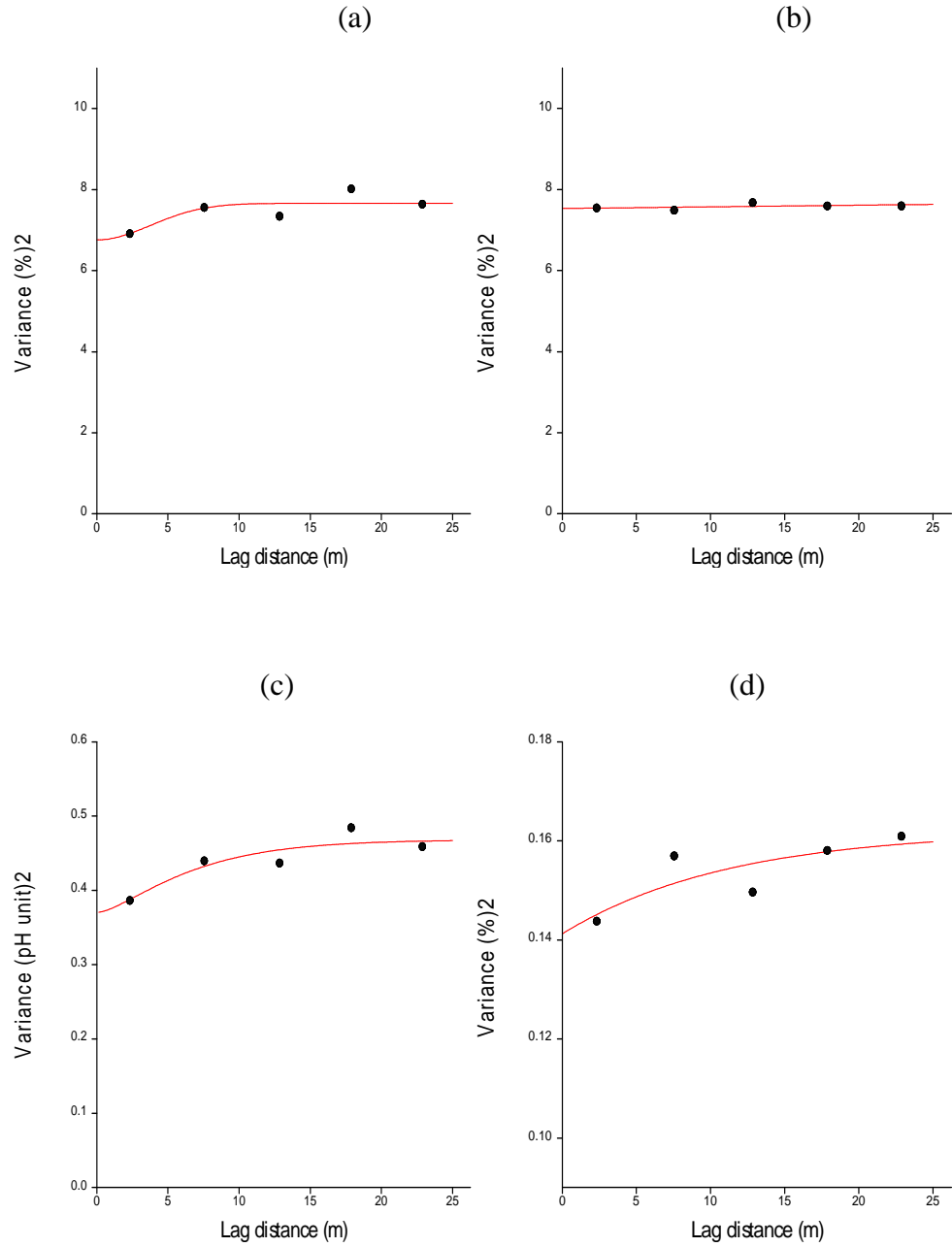


Figure 6: Omni-directional variograms (dots) and fitted theoretical functions (models): (a) Porosity (b) GWC (c) pH and (d) Organic C for topsoils

Figure 7 presents omni-directional variograms and fitted theoretical models of nitrogen, available phosphorus, exchangeable potassium and exchangeable sodium for top soils.

In Figure 7a variograms of nitrogen fitted with a linear model is portrayed. According to Table 5, variogram showed a nugget of 0.0009816.

Variogram for available phosphorus was fitted with an exponential model (Figure 8b). It showed a range of 2.8 m yielding a sill of 19.0 and nugget of 13.4. A nugget to sill (N/S) ratio of 70.5 was estimated for the variogram (Table 5).

In Figure 7c variogram for exchangeable potassium was fitted with a linear model. From Table 5, a nugget of 0.0077778 was observed.

Figure 7d shows variogram for exchangeable sodium fitted with the exponential model. A range of 6.2 m was observed, and with sill and nugget values of 0.00490 and 0.00364 respectively (Table 5).

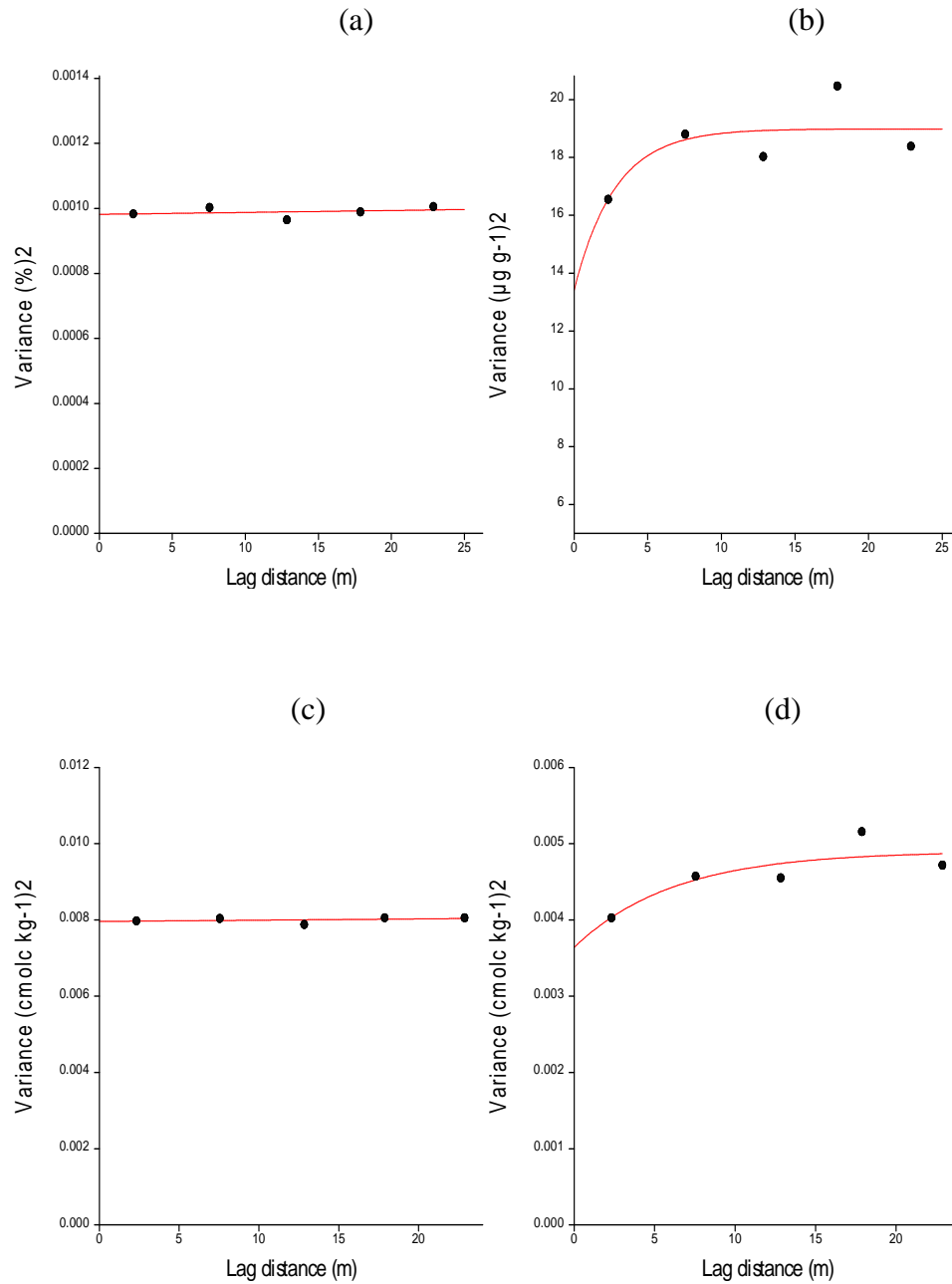


Figure 7: Omni-directional variograms (dots) and fitted theoretical functions (models): (a) total N (b) available P (c) exchangeable K and (d) exchangeable Na for top soils

Figure 8 presents omni-directional variograms and fitted theoretical models of exchangeable calcium, exchangeable magnesium, exchangeable acidity and ECEC for topsoils.

According to Figure 8a, variogram for exchangeable calcium was fitted with a linear model. It showed a nugget of 2.590 (Table 5).

Variogram for exchangeable magnesium was fitted with an exponential model (Figure 8b). According to Table 5, the variogram yielded a range, sill, nugget of 3.1, 0.15958 and 0.13493 respectively. Nugget to Sill ratio computed was 84.6.

In Figure 8c variogram for exchangeable acidity was fitted with an exponential model. From Table 5, a range of 7.3 was observed. A nugget and sill of 0.3849 and 0.2698 respectively were observed. Nugget to Sill ratio of 70.1 was estimated.

As depicted by Figure 8d, variogram for ECEC was fitted with the linear model showing a nugget of 2.5411.

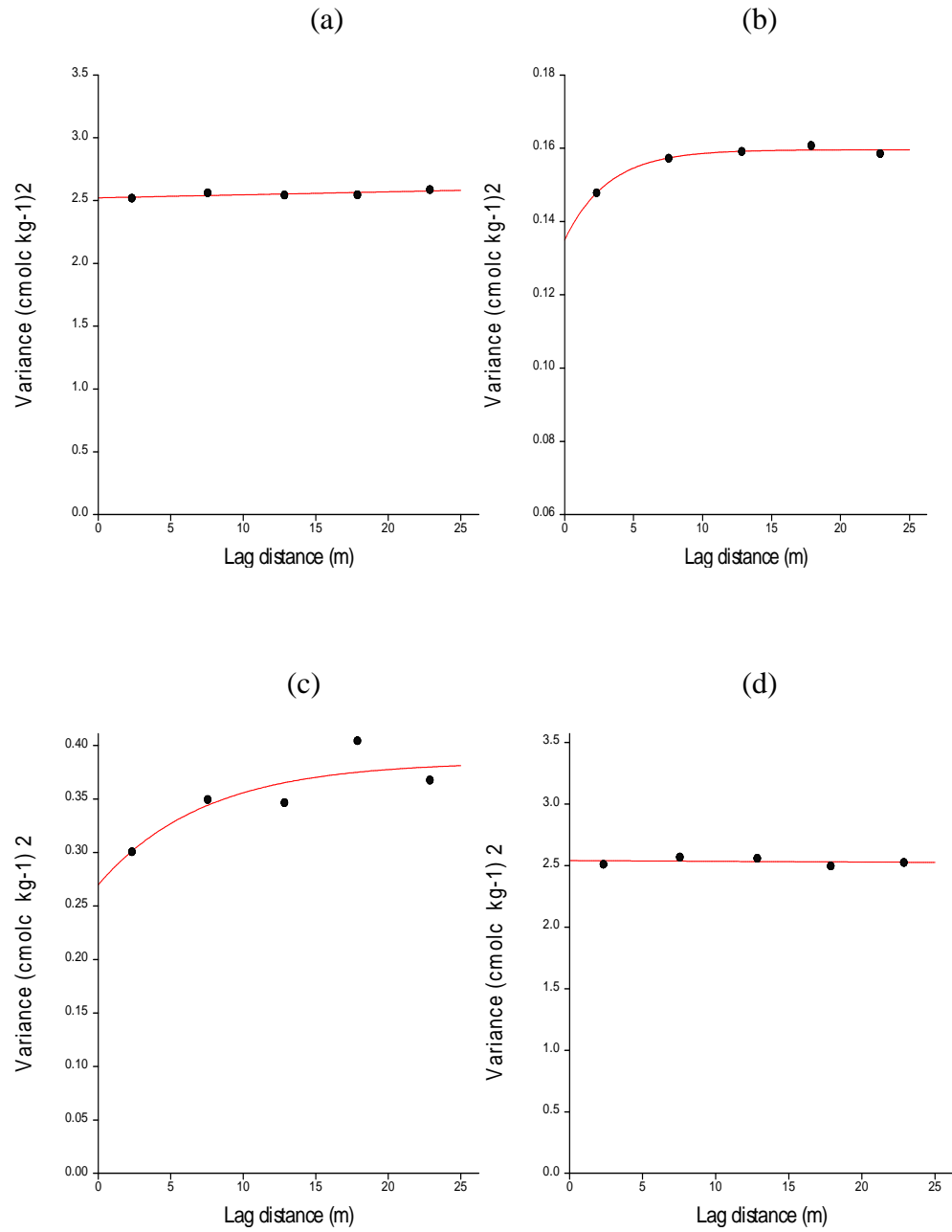


Figure 8: Omni-directional variograms (dots) and fitted theoretical functions (models) (a) exchangeable Ca (b) exchangeable Mg (c) exchangeable acidity and (d) ECEC for top soils

Figure 9 presents omni-directional variograms and fitted theoretical models of base saturation, iron, zinc and copper for topsoils.

Figure 9a portrays variogram of base saturation fitted with a pentaspherical model. According to Table 5, a range of 24.5 m was observed for the variogram. It yielded a sill of 103.91 and nugget of 95.67. Nugget to sill ratio (N/S) was computed as 92.1 %.

Variogram for iron was fitted with a spherical model (Figure 9b). It showed a range of 5.2 m yielding a sill of 65.23 and nugget of 56.0. A Nugget to Sill ratio of 85.9 % was observed.

In Figure 9c variogram for zinc was fitted with an exponential model. According to Table 5, an estimated range of 5.9 m was observed for the variogram against a sill of 0.2609, and nugget of 0.2221 respectively. A Nugget to Sill ratio of 85.1 % was estimated for the variogram.

Figure 9d shows variogram for copper fitted with the spherical model. It recorded a range of 4.0 m, sill of 0.0489 and a nugget of 0.009. A Nugget to Sill ratio of 18.4 % was observed.

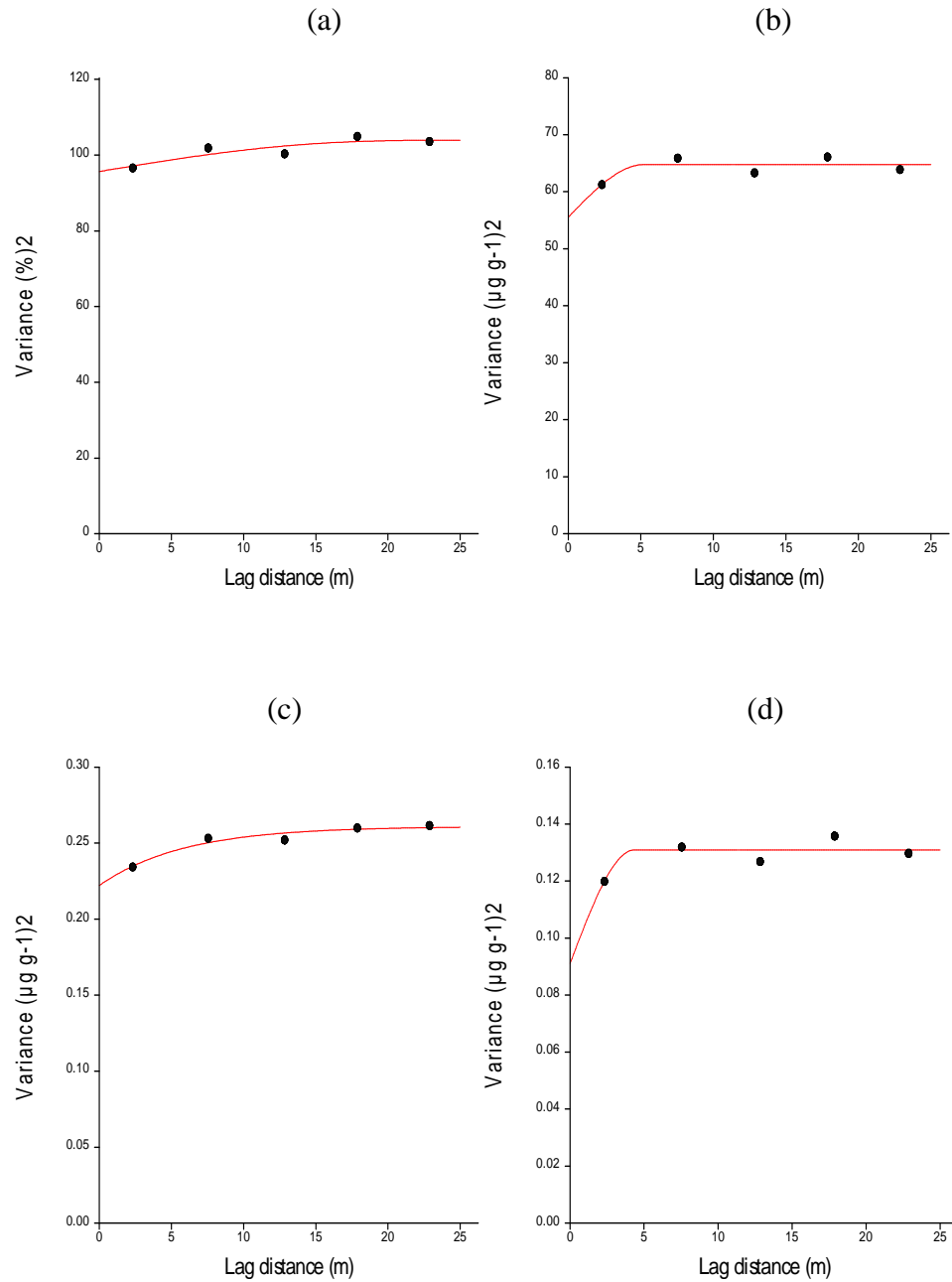


Figure 9: Omni-directional variograms (dots) and fitted theoretical functions (models) (a) Base saturation (b) Fe (c) Zn and (d) Cu for top soils

Figure 10 shows variogram for topsoil lead which has been fitted with a spherical model. It showed a range of 5.4 m, a sill of 0.0024436, and a nugget of 0.001437. Nugget to Sill ratio determined for variogram was 58.8 % (Table 5).

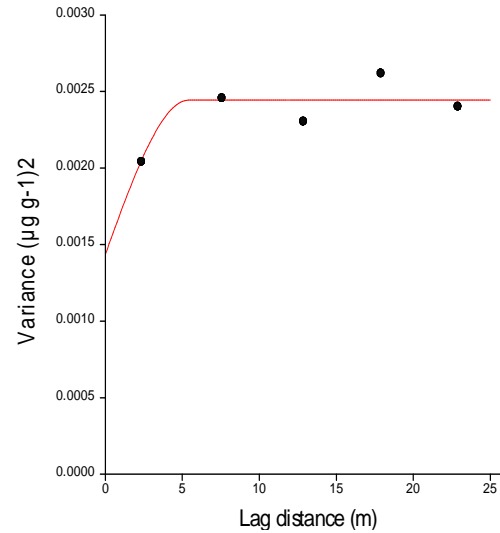


Figure 10: Omni-directional variogram (dots) and fitted theoretical function (model) of Pb for top soils

Figure 11 presents omni-directional variograms and fitted theoretical models of sand, silt, clay and bulk density for subsoils whilst Table 5 display parameters of models fitted to various properties.

According to Figure 11a, variogram for sand was fitted with a spherical model. It recorded a range, sill, nugget and nugget to sill ratio (N/S) of 9.6 m, 168, 136.76 and 81.0 (Table 6).

Variogram for silt was fitted with a spherical model (Figure 11b). From Table 6, the variogram yielded a range of 13.4 m, and a sill and nugget of 212.8 and 203.29 respectively. Nugget to Sill ratio of 95.5 was estimated.

In Figure 11c variogram for clay was fitted with a spherical model. According to Table 6, the variogram recorded a range, sill, nugget and Nugget to Sill ratio of 18.1 m, 68.9, 65.10 and 94.5 respectively.

As depicted by Figure 11d, variograms for bulk density was fitted with the linear model; it showed no range. The nugget recorded for variogram was 0.013743 which is the same as the sill.

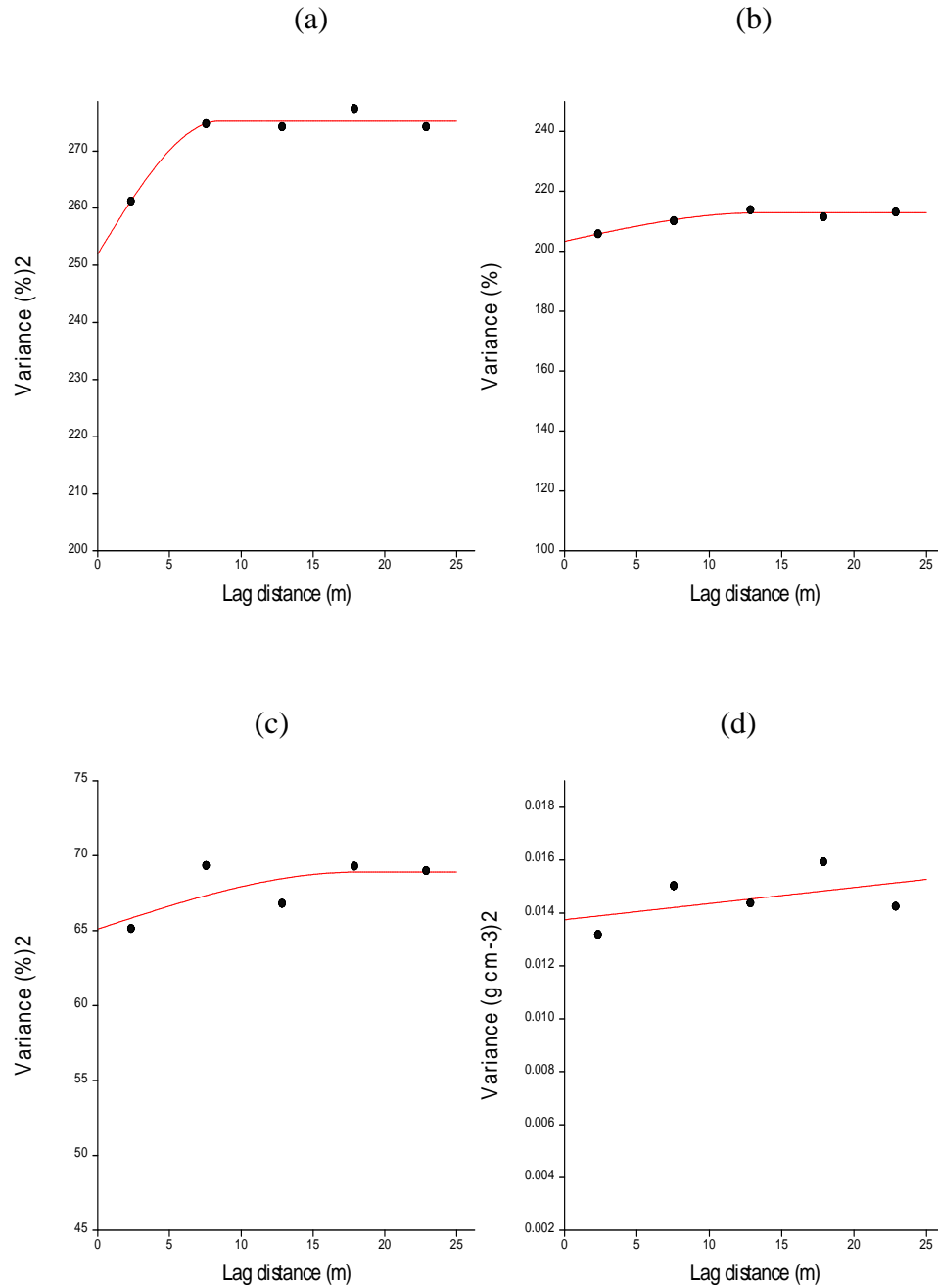


Figure 11: Omni-directional variograms (dots) and fitted theoretical functions (models): (a) Sand (b) Silt (c) Clay and (d) Bulk density for subsoils

Table 6: Estimates of variograms of soil properties studied (Sub soil)

VARIABLE	MODEL	RANGE (m)	SILL	NUGGET	N/S (%)
Sand	S	8.5	275.67	251.97	91.4
Silt	S	13.4	212.8	203.29	95.5
Clay	S	18.1	68.9	65.10	94.5
B D	L	-	-	0.013743	-
Porosity	S	6.2	10.56	9.0	85.2
GWC	L	-	-	0.0005037	-
pH	E	5.1	0.4711	0.3676	78.0
Organic C	S	23.7	0.1162	0.11	94.7
Nitrogen	BL	5.2	0.0009411	0.0008998	95.6
Av. P	E	3.3	19.0	13.4	70.5
Ex. K	L	-	-	0.0079595	-
Ex. Na	PS	21.8	0.004872	0.003852	79.1
Ex. Ca	L	-	-	2.5217	-
Ex. Mg	S	10.9	0.15943	0.14249	89.4
Ex. Acidity	E	7.4	0.3936	0.2755	70.0
ECEC	L	-	-	2.5374	-
B S	PS	24.6	101.7	93.49	91.9
Fe	PS	6.0	64	54	84.4
Zn	S	10.0	0.24395	0.21367	87.6
Cu	S	14.7	0.20545	0.18041	87.8
Pb	S	7.9	0.002081	0.001466	70.4

S = Spherical L = Linear E = Exponential N/S = proportion of sill represented by the nugget.

Figure 12 presents omni-directional variograms and fitted theoretical models of porosity, GWC, pH and organic carbon for subsoils.

In Figure 12a variogram of porosity fitted with a spherical model for top soils is portrayed. According to Table 6 a range of 6.2 m was observed for the variogram. It yielded a sill of 10.56 and nugget of 9.0. Nugget to Sill ratio was considered to be 85.2 %.

Variogram for GWC was fitted with a linear model (Figure 12b). Showing no range; it recorded a nugget of 0.0005037 (Table 6).

In Figure 12c variogram for pH was fitted with an exponential model. According to Table 6, estimated range, sill and nugget for the variogram was 5.1 m, 0.4711 and 0.3676 respectively. An Nugget to Sill ratio value of 78.0 was determined.

Figure 12d shows variogram for organic carbon fitted with the spherical model. It yielded a range of 23.7 m, sill of 0.1162 and nugget of 0.11. A Nugget to Sill ratio of 94.7 % was computed for the variogram (Table 6).

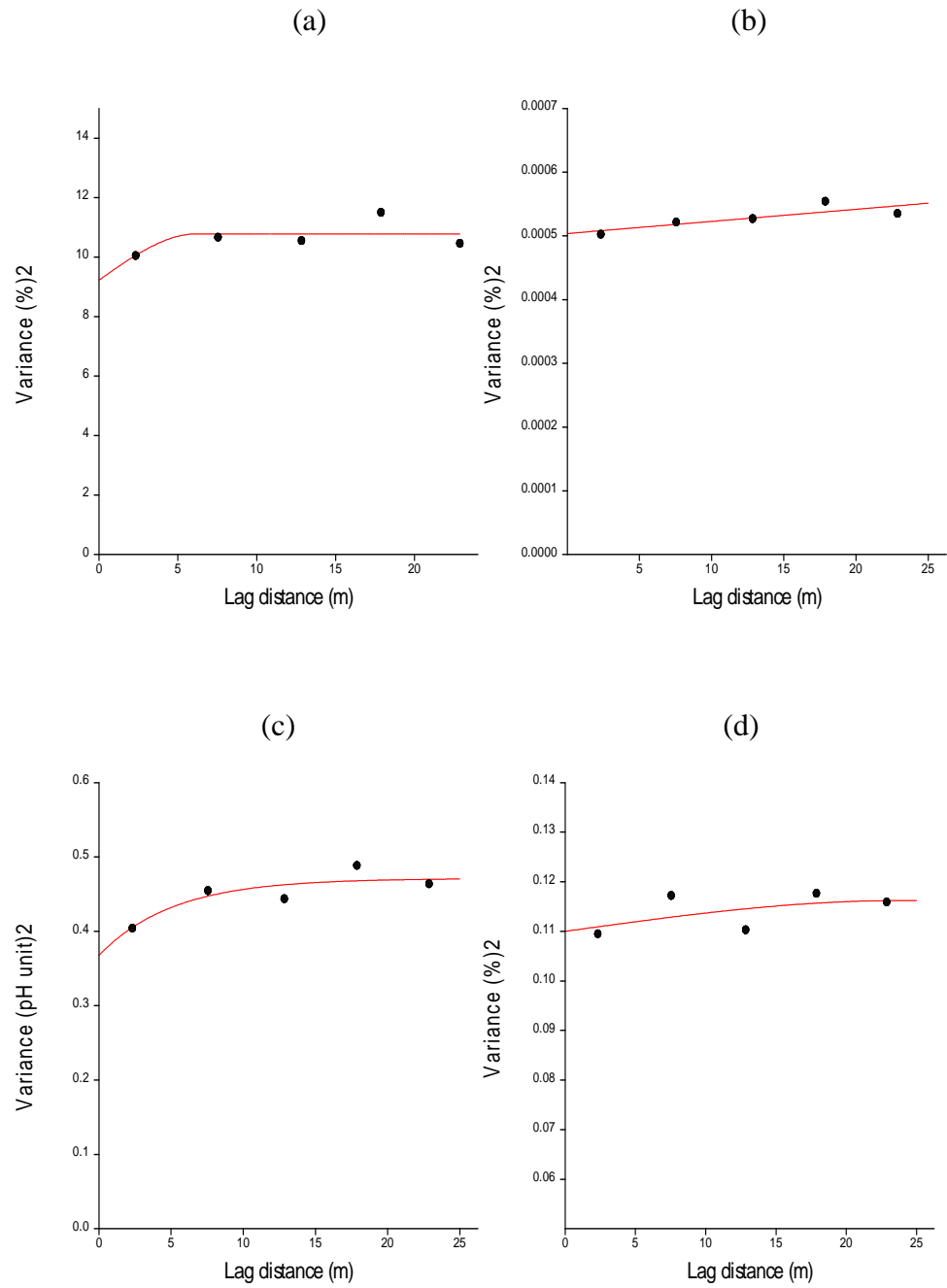


Figure 12: Omni-directional variograms (dots) and fitted theoretical functions (models): (a) Porosity (b) GWC (c) pH and (d) Organic C for subsoils

Figure 13 presents omni-directional variograms and fitted theoretical models of nitrogen, available phosphorous, exchangeable potassium and exchangeable sodium for subsoils.

According to Figure 13a, variogram for nitrogen was fitted with a bounded linear model. An estimated a range of 5.2 m for the variogram was recorded. It yielded a sill of 0.0009411 and a nugget of 0.0008998. Nugget to Sill ratio of 95.6 % was computed from the parameters.

Variogram for available phosphorous was fitted with an exponential model (Figure 13b). According to Table 6, the range and sill recorded were 3.3 m and 19.0 respectively. A nugget of 13.4 was recorded. Nugget to Sill ratio of 70.5% was determined for the variogram.

In Figure 13c variogram for exchangeable potassium was fitted with a linear model, with a nugget of 0.0079595.

As depicted by Figure 13d, variogram for exchangeable sodium was fitted with the pentaspherical model. The variogram recorded a range of 21.8 and a sill of 0.004872 against a nugget of 0.003852. Nugget to Sill ratio determined for variogram was 79.1 % (Table 6).

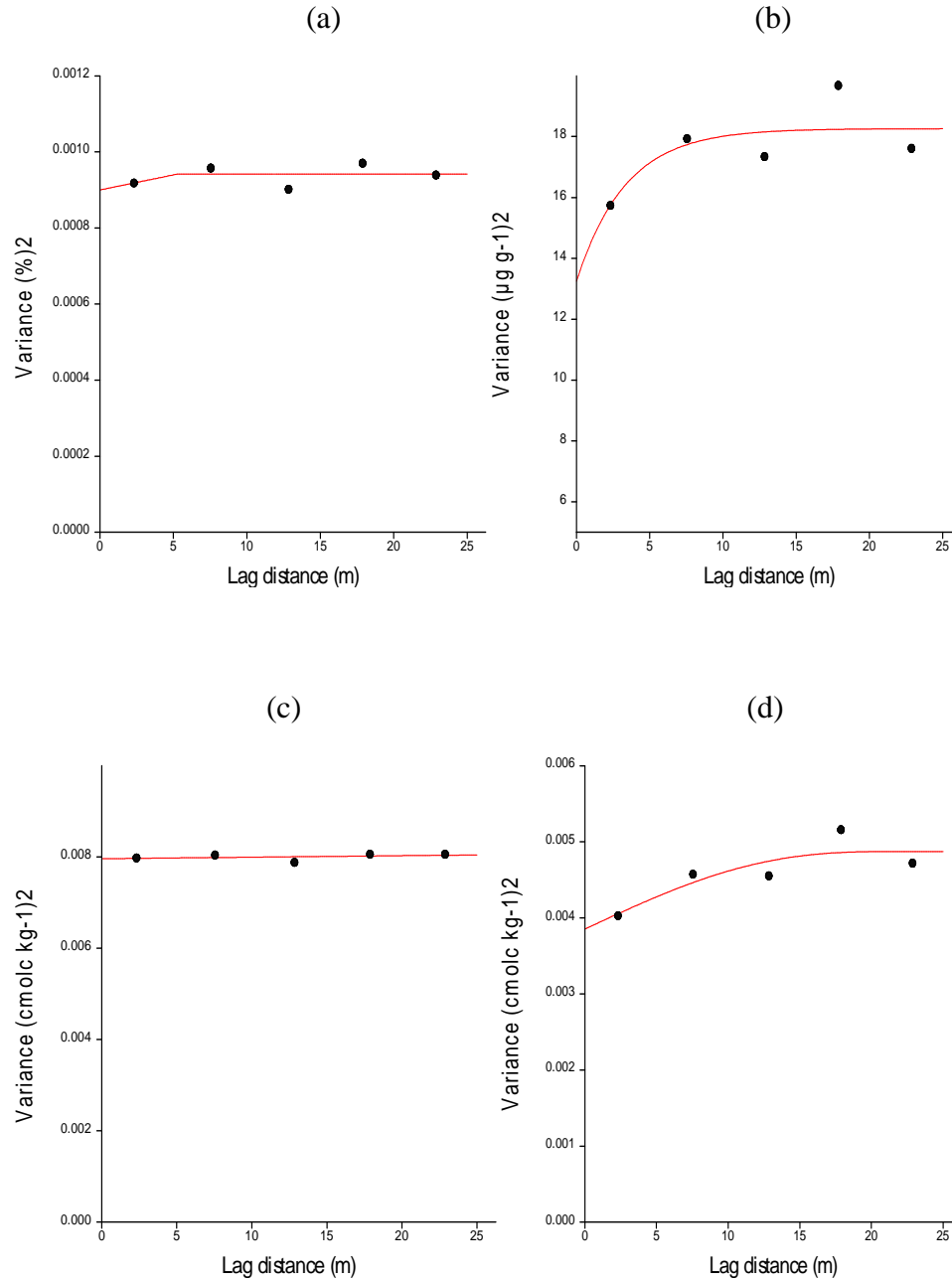


Figure 13: Omni-directional variograms (dots) and fitted theoretical functions (models) (a) total N (b) available P (c) Exchangeable K and (d) Exchangeable Na for subsoils

Figure 14 presents omni-directional variograms and fitted theoretical models of exchangeable calcium, exchangeable magnesium, exchangeable acidity and ECEC for subsoils.

According to Figure 14a, the linear model fitted the variogram for exchangeable calcium. A nugget of 2.5217 was observed for the variogram.

Variogram for exchangeable magnesium was fitted with a spherical model (Figure 14b). The variogram yielded a range, sill, nugget and Nugget to Sill ratio of 5.7 m, 135.7, 92.0 and 67.8 respectively

In Figure 14c the pentaspherical model was the best fit for exchangeable acidity. From Table 6, the variogram recorded a range, sill, nugget and Nugget to Sill ratio of 7.4 m, 0.3936, 0.2755 and 70.0 % respectively.

As depicted by Figure 14d, variogram for ECEC was fitted with the linear model with a nugget of 2.5374.

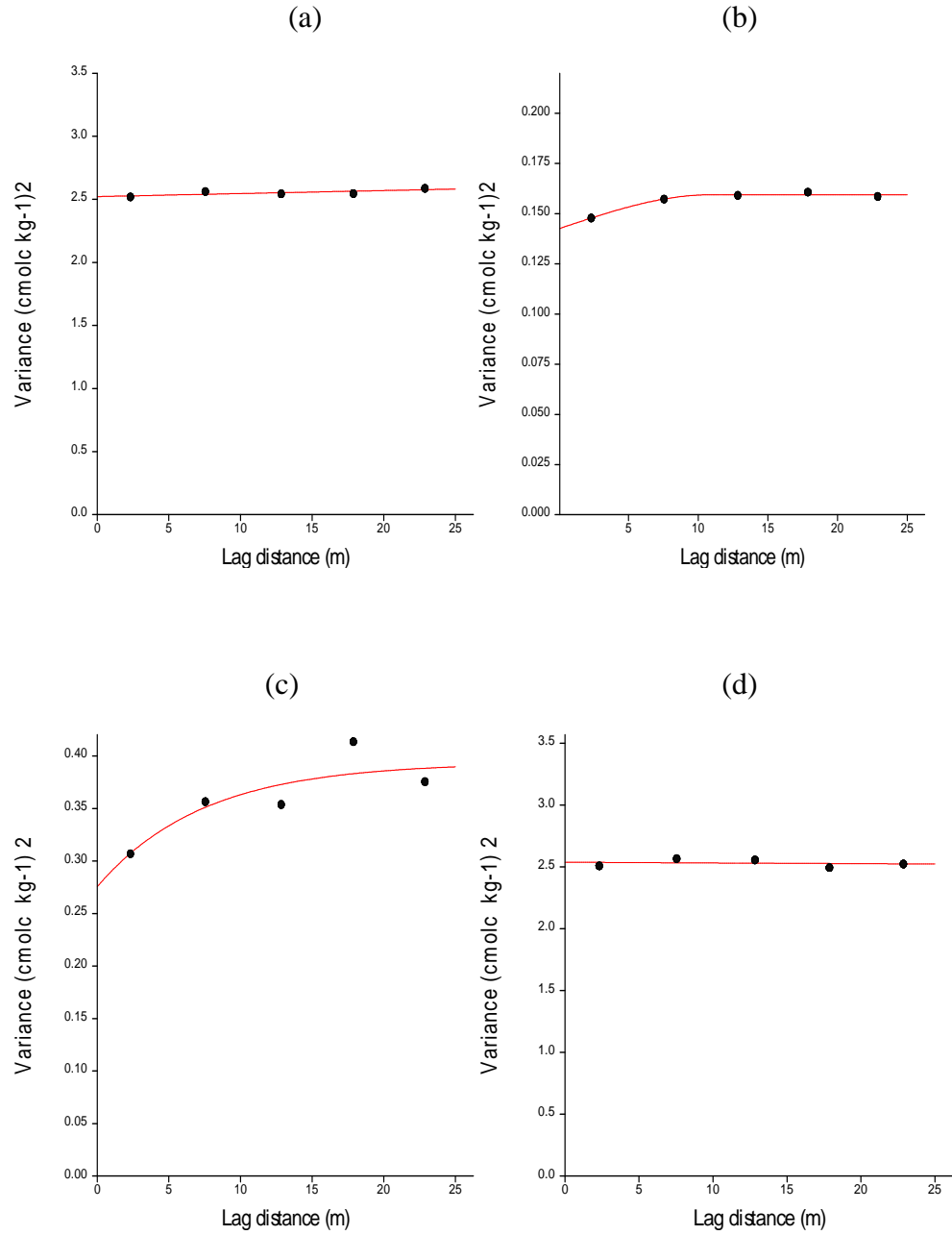


Figure 14: Omni-directional variograms (dots) and fitted theoretical functions (models) (a) Exchangeable Ca (b) Exchangeable Mg (c) Exchangeable Acidity and (d) ECEC for subsoils

Figure 15 presents omni-directional variograms and fitted theoretical models of base saturation, iron, zinc and copper for subsoils.

In Figure 15a, variogram of base saturation was fitted with a pentaspherical model. According to Table 6 a range of 24.6 m was observed for the variogram. It yielded a sill of 101.7 and a nugget of 93.49. Nugget to Sill ratio, N/S, was considered to be 91.9 %.

Variogram for iron was fitted with a pentaspherical model (Figure 15b). It showed a range of 6.0 m, yielding a sill of 64 and nugget of 54. A Nugget to Sill ratio of 84.4 % was computed (Table 6).

In Figure 15c the spherical model was the best fit for zinc with a range of 10 m. A sill and nugget of 0.24395 of 0.21367 respectively were observed. A Nugget to Sill value was considered to be 87.6 %.

Figure 15d shows variogram for copper fitted with the spherical model. It recorded a range of 14.7 m, sill of 0.20545 and nugget of 0.18041. A Nugget to Sill ratio of 87.8 % was calculated.

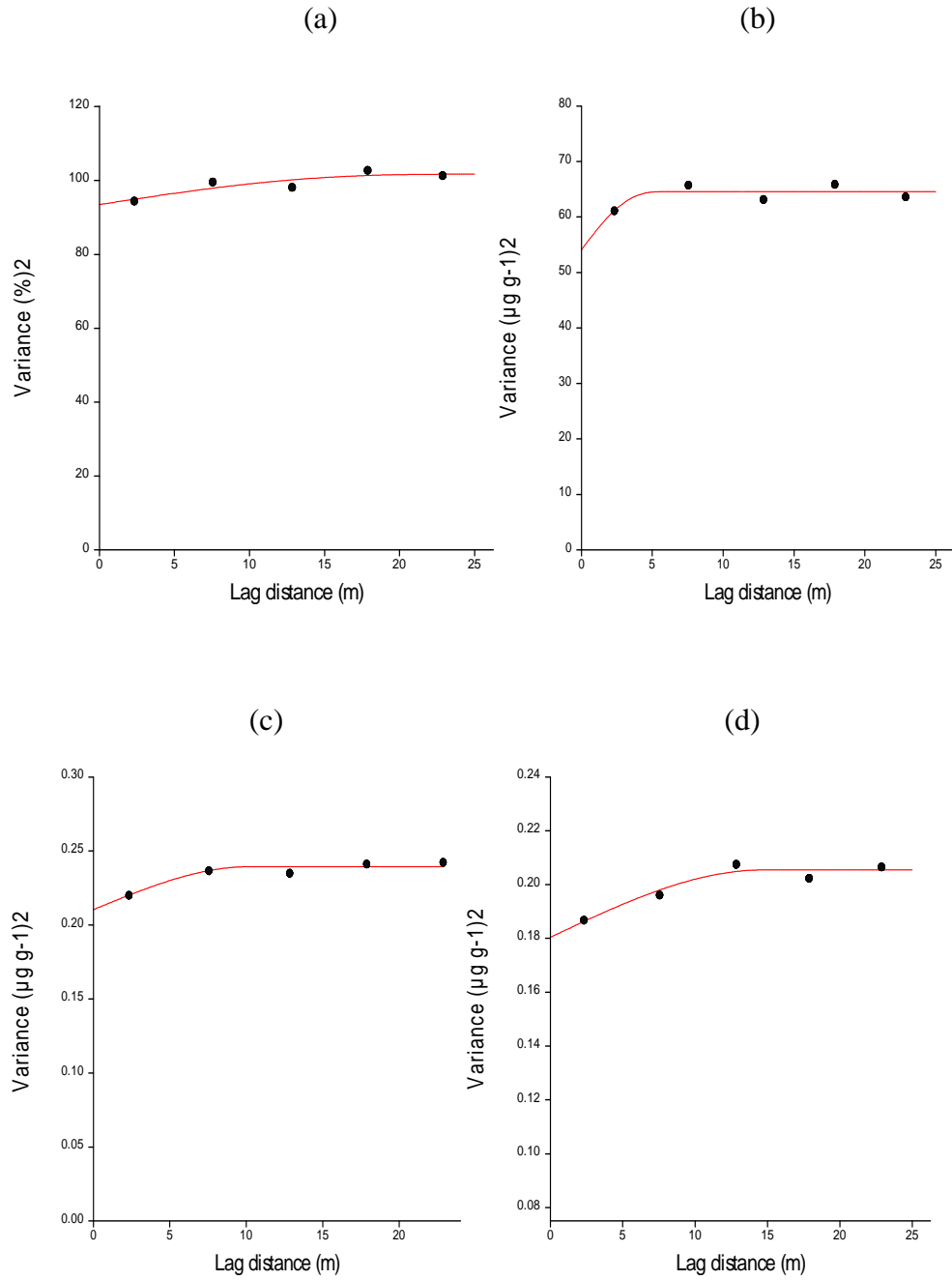


Figure 15: Omni-directional variograms (dots) and fitted theoretical functions (models) (a) Base saturation (b) Fe (c) Zn and (d) Cu for subsoils

Variogram for subsoil lead was fitted with a spherical model (Figure 16). It showed a range of 7.9 m with a sill and nugget of 0.002081 and 0.001466 respectively. Nugget to Sill ratio was found to be 70.4 (Table 6).

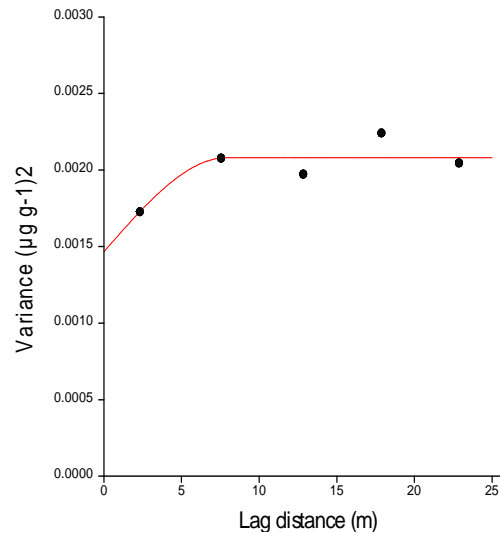


Figure 16: Omni-directional variogram (dots) and fitted theoretical functions (model) of Pb for sub soils

Spatial dependence exhibited by soil parameters varied from 2.8 m to 24.5 m for topsoil available phosphorus and base saturation respectively. The minimum distance over which there was spatial dependence was 3.3 m and this rose to 24.6 m for available phosphorus and base saturation respectively for sub soils.

For top soil variables, the lowest nugget variance (0.0001437) was recorded for lead and highest (136.76) for sand. In the case of the sub soil

variables, this was observed to be lowest (0.0008998) for nitrogen and highest for sand (251.97).

The proportion of sill (total variance) represented by the nugget was above 70 % for all variables in both soil layers, except for top soil variables silt, clay, copper and lead which recorded 67.8, 66.3, 18.4 and 58.8 respectively.

Discussion

Classical Approach

General characteristics of soil properties

The distribution of most of the soil properties for both top and subsoils were positively skewed (Tables 1 and 2). Okae-Anti and Ogoe (2006) in a study categorized coefficient of variations into low, medium and high. According to them, a variable is considered to have a low variability if the CV value is below 15 %; as medium if the CV lies between 15 and 30 %; beyond 30 %, the property depicts high variability (Appendix C). In view of this, most of the soil variables studied exhibited high variabilities. This might be broadly due to the different land use and management practices adopted at the study site as noted by Agyare (2004). However, the low CV of some of the soil properties might probably be due to the homogenizing effect that long-term cultivation and management practices might have had on those properties. The lowest CV values observed for

bulk density in the top as well as subsoil layers were within ranges cited by Warrick and Nielsen (1986) and Wilding (1988).

Soil physical properties

From Tables 1 and 2, the determined ranges of sand, for silt and clay fractions of the soils suggest the range of textural classes for on the field under study to be silty loam to sandy clay loam. However, the content of sand in the soils studied was consistent across the entire study field. This could be a direct effect of the weathering of the parent materials, which are sandstones and shales. The strong negative correlations between sand and silt were consistent with results reported by Agyare (2004). This inverse relationship could be attributed to the process of consolidation where there is the natural settling of finer soil particles due to forces of gravity. Because the size of the silt particles are smaller than that of sand, more of the silt particles fall through the soil pores into the sub layers of soils thereby increasing the amount of silt in the sub layer. This confirmed the strong negative correlation between sand and silt properties in the sub soils at the site (Table 4). Over a period of time loose, freshly cultivated soils consolidate (Rowell, 1994). However, continuous cultivation at the study site could also have partly caused great mixing of the various fractions in the top soil. This physical process might have contributed to the wide range observed for textural classes as silty loam to sandy clay loam. Ovalles and Collins (1998) in their study mentioned that a typical feature of most tropical soils is the strong negative correlation between sand and clay. The processes of eluviation and leaching might have been enhanced by the acidic nature of soils at the study site

causing the removal of soluble base cations and aluminium as well as iron compounds from the A horizon. This process, also known as ferralitization, normally leaves a region in the A horizon rich in silica sand. The above processes might likely control the variation in the textural classes across the field.

From Tables 3 and 4, the weak correlations between silt and clay fractions were in agreement with results obtained by Agyare (2004) in a similar study. However, the weak correlations between organic carbon and clay as well as silt fraction were contrary to results reported by Su et al. (2006) and Hassink and Whitmore (1997) in both temperate and tropical zones. The observation by Hassink and Whitmore (1997), that fine textured soils contained more organic matter than coarse-textured soils and that the preservation of crop residues in the soil positively correlated with its clay content, conflicts with the weak correlations between organic carbon and sand, silt and clay in Tables 3 and 4. These weak correlations between organic carbon, sand and silt as well as the clay however conform to the explanation made by Périé and Ouimet (2008), that soil organic carbon significantly decreased with increasing depth in acidic loamy to sandy loam soil textures.

Soil sampling was done in the dry season, where there were occasional rain showers. Therefore, not much moisture had been added to the soils at the site through atmospheric precipitation at the time of sampling. This might be the most probable reason for the general low levels of moisture content in soils recorded at the study site. This situation can be partly due to low soil organic matter contents, resulting in poor soil structural development with subsequently low water holding

capacity. Nevertheless, the low average porosity values for both top and subsoils obviously confirmed the low availability of soil moisture content with depth at the study site. Also, the significantly positive correlation of gravimetric water content with total nitrogen contradicts the results of Wade et al. (1996) who noted that there is no correlation between the two parameters. Soil organic carbon is found to influence moisture retention (Gollany et al., 1992).

The inverse relationship for bulk density and porosity could be attributed to consolidation and illuviation processes. As clay content of surface soils increases, structural development increases and bulk density decreases but as illuviation occurs and the pore spaces of B horizon soils are filled with clay, forming the Bt horizon, the bulk density of these layers increases. These might be the reason for the inverse relation obtained between bulk density and porosity.

The lower ranges of bulk densities in top soils compared with the subsoils is a probable indication of more disturbance of the topsoil through intensified cultivation practices and addition of organic matter which tends to loosen the soil. There is therefore, the tendency for bulk density values to increase with depth as effect of cultivation and organic matter content decrease. The mean bulk density value of 1.4 g cm^{-3} for the top soils on the field was probably an indication that the field had been subjected to years of continuous cropping. This observation confirmed range of bulk density values for recently cultivated surface soils ($0.9\text{-}1.2 \text{ g cm}^{-3}$) and ($1.1\text{-}1.4 \text{ g cm}^{-3}$) for sub surface mineral soils, not recently cultivated, but not compacted (Landon, 1991). Hence, the smaller the bulk density the more compact the soil and vice-versa.

On the other hand, the relatively high mean bulk density (1.7 g cm^{-3}) recorded for the sub soils may be due to irregular passes over the soil with heavy tillage equipment (power-driven disc ploughs) making some areas of the study site more compact than others. The mean bulk density of the sub soils was above the critical value of 1.6 g cm^{-3} , beyond which plant growth is severely limited. According to Vepraskas (1988), bulk density above 1.60 g cm^{-3} virtually stopped root elongation due to mechanical impedance and is a typical feature of compacted soils.

Also bulk density has a relationship with soil texture and is modified by structure, therefore differences in soil texture may have also contributed to the non-uniformity in the bulk density across the study field. Generally fine-textured soils (clays and silt loams) exhibit lower bulk densities than coarse-textured soils (sands). According to Rowell (1994), as structure is formed pore spaces are formed leading to an increase in porosity and a decrease in bulk density so that a loam surface soil may have a density of 1.3 g cm^{-3} .

The lower bulk density in the top soil compared to the high bulk density at the sub soil is good for crop production since the lower the bulk density the less the compaction and the better the aeration and porosity. However, there is the need for ploughing of the farm land to go a little deeper to improve upon conditions of sub soil layers on the study field whilst incorporating large amounts of organic matter which will consequently lower the bulk density. The results show that, bulk density of soils can vary significantly between soils and within a soil profile and can be influenced by land management.

Soil chemical properties

According to Tables 1 and 2, soil pH values ranged from strongly acid to slightly neutral with mean values for top and subsoils indicating a slight to moderately acidic conditions on the field. This was based on classification by Soil Survey Division Staff, (1993) (Appendix A). According to Tables 3 and 4, the soil pH correlated significantly with all other soil properties (Tables 3 and 4). These correlations support the statement made by Rowell, (1994) that soil reaction modifies physical and chemical conditions of the soil making the soil to be either suitable or unsuitable for plant growth. Sections on the field which exhibited moderate to slightly acidic conditions would be ideal for optimum microbial activity to enhance the breakdown of soil organic matter and the subsequent release of plant nutrients. According to Bray and Kurtz (1945), nutrients such as phosphorus, calcium, potassium, and magnesium are most available to plants when the soil pH is slightly acidic to slightly basic. Therefore, any further reductions in soil pH on the field could lead to a decrease in the level of these important plant nutrients in the soils. Tables 3 and 4 confirm this assertion as soil pH had positive significant correlations with these nutrients except in the case of magnesium which correlated negatively with soil pH. Also observed were positive moderate correlations between pH and base saturation as well as sodium. These pH results obtained were consistent pH obtained by Okae-Anti and Ogoe (2006) and Kpongor (2007) on tropical soils in Ghana.

Boruvka et al. (2007), noted that parent rock is an environmental factor that controlled the distribution of soil pH. The general low pH of the study field

could be ascribed to the pedogenic minerals, kaolinite clays and sesquioxides in the parent materials of the study field. These minerals normally release H^+ during rock weathering by soil water, thereby decreasing the pH of the soils. The low pH of sections on the field could also be due to internal source of acidity resulting from microbial activities in the soils. Root of crops species and microbial respiration produce carbonic acid in the soil solution which normally dissociates, releasing the H^+ ions to make the soil acidic (Rowell, 1994). Another internal source of acidity could also be H^+ release due to the decomposition of soil organic matter as a result of mineralization and nitrification aided by microbes. Low pH usually is associated with the high exchangeable acidity. This is supported by the negative moderate correlations between pH and exchangeable acidity in both soil layers.

In other related studies, Okae-Anti and Ogoe (2006) and Kpongor (2007) associated low soil pH levels to the varying effects of soil management. Accordingly, slightly acidic conditions of soils on the study site could be linked to the lower organic matter content of the soils. In that, areas on the field which exhibited relatively lower pH were probably those soils which had not received poultry manure application in previous times. These soils, which might have been under continuous cropping without fertilizer application, have their bases leached leading to increase in the levels of Al^+ ions. Hence, there is the likelihood of significant decrease in pH of these soils. Aside above influences on soil pH, crop removal and leaching of cations due to percolating rain water can also be causes for lower soil pH values. Probably heavy leaching of the soils during the rainy

season prior to soil sampling might have also caused these soils to have an acidic pH because of the net loss of the basic cations.

Organic carbon content of the soil reflects the amount of organic matter 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. Bonsu et al. (1999) and Arun (2008) 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. Metson (1961) rated the range of < 2 % for soil organic C for tropical soils as very low. In view of this, soil organic C values recorded for the soils at the study site were very low (Tables 1 and 2). According to Meteorological Station - Cape Coast, (2002), normally diurnal variations in temperature at the study site are greater in February and March, the period in which soils were taken from the field. The high temperatures favoured rapid rate of organic matter decomposition. This mineralization of the organic matter pool of the soil might have subsequently led to carbon losses and therefore the general low levels of organic carbon in the soils. However, the researchers again stated that most cultivated tropical soils were known to contain low levels of organic matter, probably due to rapid decomposition rate resulting from warm climatic conditions. This might be the probable main cause of the low carbon content of the soils at the study site. Gregorich and Anderson (1985) mentioned that soil organic carbon is an indicator of historical production and mineralization of biomass in a given location, influences fertility. The low levels of organic carbon content of the soils may also be attributed to long term effects of management including non-systematic

application of organic and inorganic manures. The very low organic carbon values recorded for some sections of the study site at the may also be attributed to low accumulation of crop residues.

The range of 0.1 – 0.2 % was rated by Metson (1961) for soil nitrogen as low. In this respect soil nitrogen values obtained in the study area can be considered as low. The low levels of total nitrogen content of the soils could be attributed to long term effects of management including nutrient removal by crops, non-systematic application of organic and inorganic manures as well as the effect of high temperatures which favour decomposition and humification of organic matter. The main source of nitrogen in the soils at the study site could be the decomposition and humification of organic matter, which is complemented by fertilizer application, and this is confirmed by the strong positive correlations between organic carbon and nitrogen (Tables 3 and 4). The observed low levels of nitrogen agree with the quoted a value of 0.3 % by Rowell, (1994) as a maximum amount of nitrogen that may exist in cultivated soils. In addition, Nye and Stephens (1962) stated that soil carbon is an important reserve for soil nitrogen. Rowell, (1994) also mentioned that amount of nitrogen in soils is closely related to the amount of organic matter. The slow breakdown of humus releases NH_4^+ which is subsequently oxidized to nitrite and nitrate, a process called denitrification. These processes, and as such, nitrogen supplies could be greatly influenced by microbial activities which are considerably reduced as a result of low pH (Landon, 1991). This subsequently could lead to the observed low levels of N (< 0.2 %) in soils at the study site.

Gijsman et al. (1996) attributed the phosphorous concentration and distribution to the extent of weathering. Phosphorous concentration and distribution in soils at the study site might have been affected by ferralitic weathering of the dominant low activity clays and sesquioxides. Higher temperatures, higher impact of rain drops and more aeration influenced favourably the rate of weathering bringing about the release of phosphorous into the soil. The surface soils over the entire study field were exposed more to higher temperatures, higher impact of rain drops and more aeration. Ferralitic weathering process favours the development of pH dependent exchange capacity in the soils leading to phosphate retention. This might be the cause of the higher content of phosphorous in the top-soils than the subsoils. Gosai et al. (2009) also observed this trend of variation in available phosphorous. The phosphorous values on the research site were consistent with that reported by Kpongor (2007). Conversely, researchers Nwoke et al. (2004), Kanabo et al. (1978) and Hoffmann et al. (2001) have reported very high values of available P ($> 40 \text{ mg kg}^{-1}$) in soils of savannah zones of West Africa.

Landon (1991) quoted a range values of $< 3 \text{ mg kg}^{-1}$ as acutely deficient, 3 to 5 mg kg^{-1} as deficient, 6.5 to 13 mg kg^{-1} as marginal, 13 to 22 mg kg^{-1} as adequate and $> 22 \text{ mg kg}^{-1}$ as rich for phosphorous in central African soils. With respect to this the mean values of available phosphorous obtained at the research site can be considered to be marginal (Table 1 and 2). The reasons for areas which recorded deficient values could be attributed to long-term removal of phosphorous by crops and non-systematic application of organic and inorganic manures. Large

amounts of phosphorous are taken up and incorporated into the system of root crops like cassava and potatoes (Howeler, 2001). Therefore, the harvesting of these crops might have led to the reduction of phosphorous levels in certain sections of the field where such root crops are usually cropped and therefore the little phosphorous left in the crop residues is released back into the soil through decomposition processes. Rhodes (1995) and Vlek et al. (1997) noted that phosphorous mainly got lost from the soil through crop harvest and only little was left in residues for recycling. The marginal levels of available phosphorous obtained at the study site is consistent with results from studies carried out in the savannah zone of Ghana by Abekoe and Tiessen, (1998).

According to Smeck (1985), the amount and distribution of phosphorous in tropical soils was mainly dependent on the type of parent material. However, Abekoe and Tiessen (1998) considered position in a landscape as a cause for this distribution. The study site was characterized by gently undulating slopes which might have enhanced the erodibility of the soils during the rainy season before the sampling period. Hence, the transfer of eroded soils containing phosphorus by run offs from upper slopes to down slopes might also be a cause of variation in phosphorous levels at the different sampling points.

The potassium (K) supply in soil resulted from the natural processes of weathering of primary minerals and dissociation from colloidal clay and humus. The local climate at the study site might have influenced the availability of exchangeable K because of high temperatures and also previous rainfalls prior to sampling period that might have encouraged the decomposition of organic manure

and subsequently leading to the release of potassium. The released of potassium, if not taken up by plants, after it had been translocated out of the soil profile, are leached. Landon (1991) assigned ranges of $< 0.1 \text{ mg kg}^{-1}$, $0.1 \text{ to } 0.2 \text{ mg kg}^{-1}$, $0.2 \text{ to } 0.3 \text{ mg kg}^{-1}$ and $> 0.3 \text{ mg kg}^{-1}$ to groups of deficient, marginal, adequate and rich sandy loams respectively. In line with this, mean values of potassium obtained at the site suggest that exchangeable K is adequate and ranging from deficient to rich in some sections of the field (Tables 1 and 2). Acquaye, (1973) observed that the total K content in tropical soils may be quite low because of the origin of the soils, high rainfall and high temperatures. However, from Tables 1 and 2 the adequate levels of potassium at the site might have been contributed by sources like the patches of ash resulting from localized burning of crops residue. These processes have direct influence on the soil pH, as is indicated by the exchangeable K correlated best with pH for both soil depths. Some of the soils recorded values above the K amount of $0.2 \text{ cmol}_c \text{ kg}^{-1}$ quoted by Rowell (1994) as tolerant for most crops. This could be possibly from uneven distribution of organic matter on the study site.

Asamoah (1973) reported that the soils on the study site were highly weathered and leached of their bases and are therefore acidic. Generally, the availability of properties such as exchangeable bases is influenced by exchangeable acidity while Effective Cation Exchange Capacity (ECEC) and base saturation remain dependent on exchangeable acidity. However, all these properties are influenced in one way or the other by soil pH, since Rowell (1994), observed that very low pH levels in the soil bring about deficiencies in

exchangeable calcium. Hence, the relatively high levels of calcium obtained might have been favoured by the slight to moderate pH conditions on the study. From Tables 1 and 2, the mean ECEC values for both depths were above the average limit of $5 \text{ cmol}_c \text{ kg}^{-1}$ and this is common for tropical soils (Landon, 1991). This can be attributed to high pH and high base saturations as well as with high levels of exchangeable calcium in the soils. This observation is supported by the strong correlations between ECEC and Exchangeable calcium, and ECEC and base saturation for both top and subsoils (Tables 3 and 4). The increasing base saturation with increasing depth across the study site could be due to leaching of the exchangeable bases therefore bringing about increase in the concentration of these bases in the sub layer. This trend might have been contributed by the sloping to gently undulating nature of the research site (Appendix E). Landon (1991) classified percent base saturation (BS) values below 50 % as low and that above as high, corresponding to less fertile and fertile soil. In view of this, the soils could be classified as less fertile; since they generally exhibited low base status across the field. The weathering processes of kaolinite clays and sesquioxides might have lead to the leaching out of bases in the soils. This process favours the release more aluminium ions (Al^{3+}) which creates acidic conditions in the soils and subsequently leaching of soil nutrients. This supports the assertion by Asamoah, (1973) that the soils at the site are highly weathered and leached of their bases and are therefore acidic. From Tables 3 and 4, exchangeable calcium showed relatively higher levels than the other exchangeable bases. Areas of the site which recorded slightly higher base

saturation values might have been influenced by the relatively higher levels of exchangeable calcium. This was confirmed by the high degree of association between exchangeable calcium and base saturation (Tables 3 and 4). The significant positive correlations between pH and base saturation as well as exchangeable calcium were in agreement with by Adamson et al., (1996).

Landon, (1991) stated that all micronutrients become more available with increasing acidity. However, the author was of the view that copper (Cu) availability was less influenced by pH than the other micronutrients. Rowell (1994) noted that in tropical soils, iron and aluminium oxides and hydroxides were dominant. However, from Table 3 the topsoil copper shows weak positive correlation with pH, but exhibiting inverse relationships with iron (Fe) and zinc (Zn). High levels of iron and zinc are found to induce copper deficiencies (Olsen, 1972; Landon, 1991). From Tables 3 and 4, it was observed that mean levels of Fe and Zn were higher than that of Cu. Landon (1991) emphasized the adsorption of Cu^{2+} ions by clay minerals and is reflected in Table 3 that shows copper correlated weakly and negatively with clay fractions of the soils. Therefore with increase in clay fractions of the soil, copper level reduces as Cu^{2+} ions are adsorbed by the clay minerals. This adsorption process might have contributed marginally to the availability of the copper at the research site. This behaviour of copper might be the reason why Landon (1991) stated that though the availability of copper decreases slowly with increasing pH, the nature of the interaction is not completely understood. However, the high levels of iron at the research site can be attributed to the presence of the dominant mineral components sesquioxide in

the parent material (sandstones, shales and conglomerates) at the site. According to Asamoah, (1973), the soils at the study site are partly dominated by low activity of kaolinite clays and sesquioxides (Asamoah, 1973). Therefore, the decomposition or weathering of the sandstones and shales might have led to the release and the accumulation of iron rich sesquioxide minerals as residual products. This might be a probable cause for the general high levels of iron recorded for the site. This confirms the statement made by Robert (1979) and Rowell (1994) that soils along tropical and sub tropical coastlines and river deltas usually contained significant quantities of iron (II) sulphides. Levels of lead might have been dependent on base saturation and exchangeable acidity as it negatively correlated with base saturation and positively correlated with exchangeable acidity. The range of values, 0.5-0.1 $\mu\text{g g}^{-1}$, 0.3-0.8 $\mu\text{g g}^{-1}$ and $>10 \mu\text{g g}^{-1}$ has been quoted by FAO (2008) as low, average and very high for soil zinc, copper and iron respectively. With respect to these mean values recorded for soil zinc and copper can be said to be low and moderate respectively whilst mean values of iron is considered high in the soils. According to Tables 3 and 4, micronutrients tend to be affected by the level of pH of soil. The significant inverse relationships found between the micro nutrients (Zn, Fe and Pb) and pH supports the low levels of micronutrients at the study site. Aluminium oxides in soils are known contribute largely to the acidic conditions in soils causing reduction in the levels of soil micronutrients (Rowell, 1994). Exchangeable acidity, a reflection of the amount of aluminium oxides in soils was found to have weak inverse relationships between organic carbon content of the soils and Ex. Ac (Tables 3 and 4). This implies that Ex. Ac

increases with reduction in O.C. Soil organic matter or humic substances have been found to influence micronutrients availability through chelating, which can either increase or decrease the available micronutrients (Mortvedt et al., 1991; Mackowiak et al., 2001). Chelation is a natural process involving organic substances in the soil control the leaching out of micronutrients. However, the generally low levels of organic carbon might have also favoured the leaching out of micronutrients in the soil.

Incorporation of sufficient organic matter into the soil would be useful in maintaining and improving soil physical and chemical properties and counteracting the adverse effects of other soil properties on soil structure. Management practices, such as growing suitable legumes or grasses for short-fallows, application of organic manures, green manuring and incorporation of crop residues could be ideal to replenish soil nutrients.

Geostatistical Approach

Geostatistical patterns of soil properties

Observed spatial patterns demonstrated both spatial dependence (bounded variograms) and non-spatial dependence (unbounded variograms) of the soil variables. The latter implies lack of spatial dependence in these soil properties at the chosen scale of sampling. In other words, the model depicts unstructured short-distance or microvariability which cannot be resolved with the sampling distance chosen or for which one cannot establish clear causes (Figures 6b, 7a, 7c, 8a, 8d, 12b, 13c, 14a and 14d). Generally, could be from measurement errors or

unexplained variation over distances much smaller than the closest sampling distance. This implies that even the least sampling interval of 5 m was not suitable for determining the spatial structure of these soil properties fitted with the unbounded models. A less than 5 m field scale sampling unit might be ideal to reveal any structure in the variation.

Common sources of random or indeterminate variation are heterogeneity in parent material, biotically related tree-throw, activities of earthworm, mound building animals, and animal droppings or cultural practices such as uneven distribution of fertilizer, manure or lime (Beckett and Webster, 1971; Dobermann et al., 1995; Ellert and Gregorich, 1996; Adderley et al., 1997).

On the other hand, the other models which showed spatial dependence can be attributed to systematic variations where the structured changes in soil properties were as a result of soil-forming factors such as parent material and imposed soil management processes and land use on different areas of the study site (Figures 5a-d, 6a, c and d, 7b and d, 8b and c, 9a-d, 10, 11a-c, 12a, c and d, 13a, b and d, 14b and c, 15a-d, 16). The steepness of the initial slope indicates the intensity of change in variance of a property with distance and the rate of decrease in spatial dependence. For instance, for soil properties fitted with exponential models, this intensity of change is higher than in those properties fitted with spherical models. Hence, making the properties fitted with the spherical models more stable than those fitted with exponential models.

The study revealed that more stable properties like sand, silt and clay were fitted with spherical models as against exponential model for less stable

properties. This compared favourably with literature (Okae-Anti and Ogoe, 2006). Okae-Anti and Ogoe (2006), fitted spherical models to sand, silt and clay noting that inherent soil properties usually showed more stable spatial structures, with the spherical variogram fitting best.

According to Tables 1 and 2, organic carbon, porosity, moisture content and bulk density decreased with depth leading to less microbial population and subsequently less pedogenic processes to bring about more instability in soil properties in the sub soil than in the top soils. However, land management activities could also be a cause for this occurrence. The observation is comparable to that made by Agyare (2004) who accredited the situation to less soil disturbance in the sub soil zone through land management activities. This might be the probable explanation for the observed increases in distances over which spatial dependence was experienced. The topsoils have been exposed more to pedogenic processes comprising physical, chemical and microbial activities.

Cambardella et al. (1994), in their study mentioned that generally, the nugget-to-sill (N/S) ratio can be used to classify the spatial dependence of soil properties. A variable is considered to have a strong spatial dependence if the ratio is less than 0.25; a moderate spatial dependence if the ratio lies between 0.25 and 0.75; otherwise, the variable has a weak spatial dependence. In view of this, the soil variables studied exhibited weak spatial dependences.

The very high N/S ratios recorded for soil properties depict either a high proportion of experimental errors or that the variability pattern in these soil properties was not captured even at the lowest scale of measurement. This might

be the most probable explanation for the high nugget values recorded for sand in both top and subsoil layers. It is recommended that future research should consider sampling distances below the field scale of 5 m considered for the study in order to reduce the nugget to sill ratios and also reveal the possible spatial patterns of these soil properties for soil management. However, average range values of 6.8 m and 11.7 m for topsoils and subsoils respectively is a clear indication that variables at the subsoils were generally more spatially correlated than at the topsoils. That meant that topsoils had been greatly disturbed probably due to cultivation. Different sampling intervals of 6.8 m and 11.7 m respectively must be used in order to reveal extra probable spatial patterns of those soil properties which exhibited spatial dependence.

Spatial variability in soil physical properties on the field may be due to natural pedogenic processes like consolidation, eluviation-illuviation and erosion. It can also be concluded that the variation in soil properties over the entire study field was due to intrinsic (soil-forming processes) and extrinsic factors such as soil fertilization and cultivation practices. Generally, the uneven distribution of parent materials on the field as well as soil management and land use patterns on different areas of the study field could be factors affecting the spatial distribution of chemical soil properties on the study site.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATION

Summary

The knowledge of spatial variability of soil properties remains a major necessity so far as land use, soil management and experimental set-ups are concerned. However, there is lack of adequate information pertaining to this subject. This has necessitated the study of the spatial variability of selected physico-chemical properties at the University of Cape Coast School of Agriculture Teaching and Research Farm.

The stratified random sampling design was employed in the study obtaining a total of 1,510 samples over the 2.17 ha research site from two depths 0-10 cm and 10-20 cm at each sampling point. The Geographic Positioning System (GPS) was used in recording coordinates of each sampling point. Twenty-one soil properties namely sand, silt, clay, bulk density, porosity, gravimetric water content, pH, organic carbon, nitrogen, available phosphorous, effective cation exchange capacity, iron, copper, zinc, lead, base saturation, exchangeable acidity, exchangeable potassium, sodium, calcium and magnesium were determined on the samples.

Classical and geo-statistical analyses were performed on the raw data. The former showed levels and ranges of parameters as well as their degree of

variations and correlations amongst them. Geostatistical analyses presented the spatial patterns for the soil properties. The behaviour of soil attributes was evaluated through the functions fitted to the experimental semivariograms.

Conclusions

About 57 % of both physical and chemical soil variables studied exhibited high variabilities. This was broadly attributed to the different land use and management amidst different soil series on the study site. The rest which showed lower variabilities was ascribed to the homogenizing effect of the long-term cultivation and homogenous management on these properties. The study identified random and systematic variations as the main sources of variations in soil properties.

The study also highlighted consolidation and eluviation-illuviation of silicate clays as most probable processes responsible for the inverse relationship between bulk density and porosity. The mean bulk density of the sub soils was above the critical value of 1.6 g cm^{-3} , beyond which plant growth is severely limited.

Generally, the pH of the study site ranged from strong acid to slightly neutral conditions with recorded values ranging between 4.1 and 6.7. The pH was found to have correlated significantly with all the other soil properties studied. About 60 % and 40 % of the soil variables studied showed positive and negative correlations respectively with pH for top soils. The same observation was made for sub soils.

The soils were generally very poor in macronutrients (organic carbon, phosphorus, nitrogen, and potassium) with organic carbon and nitrogen being the most deficient nutrients. These low levels of the nutrients were mainly attributed to the rate of decomposition and humification of organic matter as well as the long term effects of management including nutrient removal by crops, non-systematic application of organic and inorganic manures, the isolated burning and the effect of high temperatures and intense rainfall leading to mineralization of the organic matter pool of the soil. Some of the soils recorded high values above the K amount of $0.2 \text{ cmol}_c \text{ kg}^{-1}$ in soil considered tolerant for most crops.

Soils were generally deficient in micronutrient levels. This could be attributed partly to the generally low pH of study site and low content of other derived soil parameters such as exchangeable acidity and base saturation. However, iron deviated from this trend as it recorded extremely high ranges across several sections of the study site. These high levels were probably due to the accumulation of iron rich sesquioxides which are residual products from decomposition of the parent rocks.

Variables at the subsoils were generally more spatially correlated than at the topsoils with average range values of 6.8 m and 11.7 m respectively. That meant that topsoils had been more greatly disturbed than subsoils probably due to cultivation.

Spherical models fitted for sand, silt and clay confirmed that these variables are *in situ* variables coming directly from parent materials. Spherical

models fitted for iron, zinc, copper and lead confirm that these are inherent variables derived possibly from minerals of parent rocks.

About 76 % of both physical and chemical variables studied exhibited spatial dependence. The rest which showed no spatial dependence was mainly ascribed to measurement errors and variation not captured within distances smaller than the closest sampling distance. It is evident from this study that spatial structures existed in most of the soil properties at the field scale in the study area.

The null hypothesis that soil properties on the farm were not spatially structured is rejected.

Recommendation

It is recommended that future research should consider different sampling intervals for topsoils and subsoils in order to reveal more spatial structures. Sampling within separating distances of 6 m and 11 m for topsoils and subsoils respectively are recommended.

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APPENDIX A

The descriptive ranges of soil pH	
Ultra acid	< 3.5
Extremely acidic	3.5- 4.4
Very Strongly acidic	4.5- 5.0
Strongly acidic	5.1- 5.5
Moderately acidic	5.6-6.0
Slightly acidic	6.1-6.5
Neutral	6.6- 7.3
Slightly alkaline	7.4- 7.8
Moderately alkaline	7.9- 8.4
Strongly alkaline	8.5 – 9.5
Very strongly alkaline	> 9.5

Source: Soil Survey Division Staff, 1993.

APPENDIX B

Critical range for extractable micronutrients levels in soils

Micronutrient	Concentration ($\mu\text{g g}^{-1}$)				
	Very Low	Low	Medium	High	Very High
Copper	0.0-1.0	0.1-0.3	0.3-0.8	0.8-3.0	>3.0
Iron	0.0-2.0	2.0-4.0	4.0-6.0	6.0-10.0	>10.0
Manganese	0.0-0.5	0.0-1.2	1.2-3.5	3.5-6.0	>6.0
Zinc	0.0-0.5	0.5-1.0	1.0-3.0	3.0-5.0	>5.0

Source: FAO, (2008)

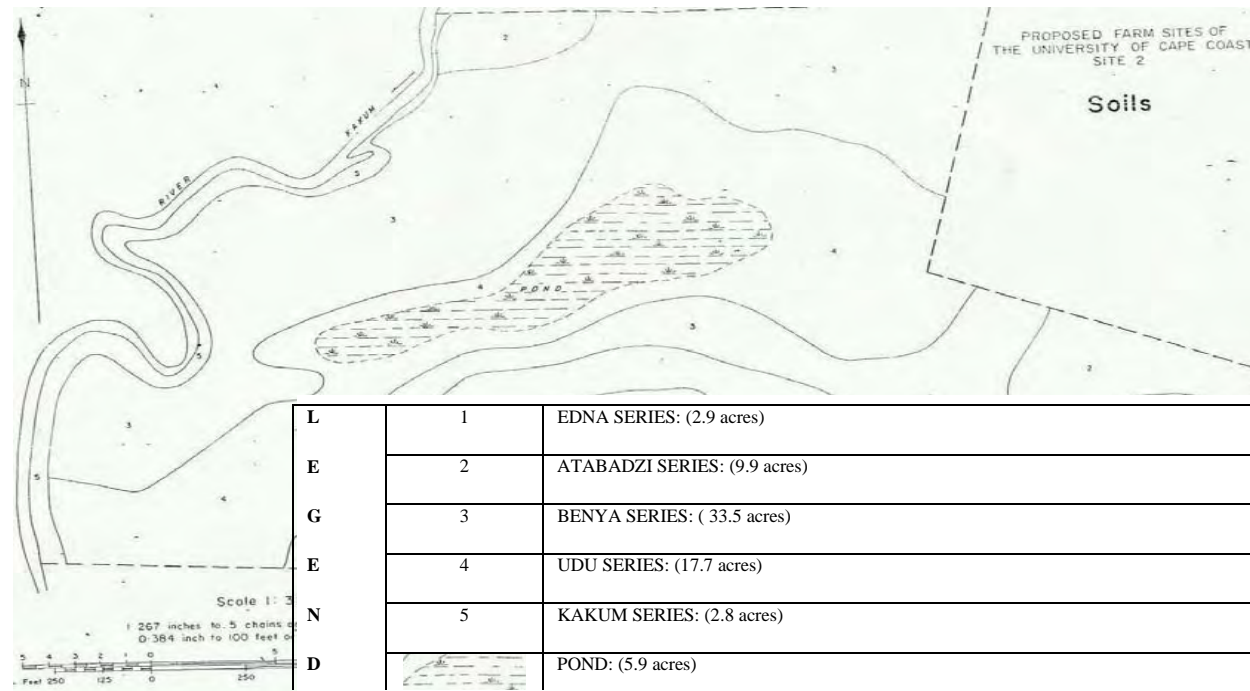
APPENDIX C

Categorization of coefficients of variation

	Low	Medium	High
Category of CV (%)	<15	15-30	>30
Suggested limit of spatial dependence (range) /m	<25	25-50	>50

Source: Okae-Anti and Ogoe, (2006)

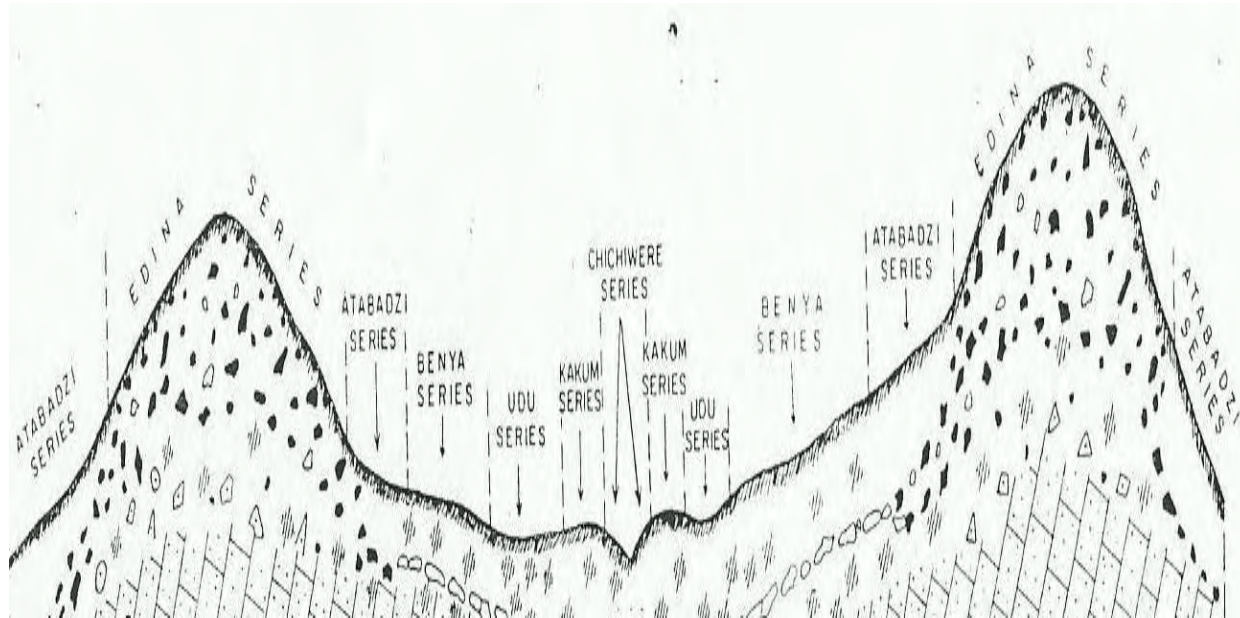
APPENDIX D



Map showing distribution of soil series at the study site

Source: Asamoah (1973)

APPENDIX E



Edina – Udu Compound Association (Diagrammatic section showing topographic sequence of soils with Profile diagram)

Source: Asamoah (1973)