PHYSICO-CHEMICAL CHARACTERIZATION AND SPATIAL VARIABILITY OF SOILS IN THE RESEARCH BLOCK AT UNIVERSITY OF LIMPOPO EXPERIMENTAL FARM

by

KOPANO CONFERANCE PHEFADU

MINI-DISSERTATION

Submitted in (partial) fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE)

in the

FACULTY OF SCIENCE AND AGRICULTURE

(School of Agricultural and Environmental Sciences)

at the

UNIVERSITY OF LIMPOPO

SUPERVISOR: DR. FMG VANASSCHE

CO-SUPERVISOR: PROF. FR KUTU

2015

DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

__________________ 18/09/2015

Phefadu, KC (Mr) **Date**

ABSTRACT

Soil characterization provides detailed information about the spatial variability within a given area; and thus allows for the implementation of appropriate crop and soil management practices that align with the soil condition. The objective of this study was to investigate the spatial variability of soil physical and chemical properties in the research block at the University of Limpopo experimental farm, Syferkuil. Twelve soil profile pits were dug across the research block at selected areas. Soil samples were collected from each diagnostic horizon of every soil profile and analysed for selected soil physical and chemical properties. Soil depth, structure and consistency were documented in the field. The depth of the profiles ranged from 28 cm to 100 cm and the soils were generally categorized as shallow soils. The soil colour (dry) varied from dark brown to very dark greyish brown. The structure and consistency were predominantly blocky and firm or friable respectively. The bulk densities ranged from 1.20 g/cm^3 to 1.80 g/cm^3. Sand, silt and clay content were in the range 61-87%, 1-15% and 7-27%, respectively, the soils were broadly categorised as sandy loam, loamy sand and sandy clay loam.

The average pH_W and pH_{KCl} were slightly alkaline and slightly acidic respectively. Bray-1 P, electrical conductivity, potassium, magnesium, calcium, manganese, sodium, zinc and effective cation exchange capacity differed significantly ($p<0.05$) with depth while organic carbon content and effective cation exchange capacity differed significantly ($p<0.05$) across the profiles. The mean values for pH, electrical conductivity, calcium, magnesium, sodium, iron, copper, effective cation exchange capacity (ECEC) and organic carbon were higher in the subsoil than in the topsoil while mean values for Bray-1 P, potassium, zinc and manganese were higher in the topsoil. The electrical conductivity, Bray-1 P, exchangeable potassium and sodium were the most variable soil chemical parameters. Organic carbon, exchangeable calcium and magnesium, ECEC, extractable iron and zinc were moderately variable; while pH, extractable copper and manganese were least variable. The variables that were normally distributed included pH, organic carbon, Bray-1 P, extractable iron, copper and zinc; while electrical conductivity, effective cation exchange capacity, extractable manganese, exchangeable calcium, magnesium, sodium and potassium were not normally distributed.

There exists a considerable level of spatial variability in soil physical and chemical properties within the research block; and the soils are generally shallow. Of all the measured parameters, electrical conductivity, Bray-1 P, exchangeable potassium, calcium and sodium as well as extractable iron and zinc showed a huge percent of variation across the field. Soil variability maps indicated the degree of variability within the research block. The spatial variability of the characterized parameters was significant across the research block. A correlation study was conducted to investigate the relationship between the measured soil physical and chemical properties. Regular soil analyses should be conducted to avoid failure/delay of experiments. It is recommended that inputs such as irrigation and fertilizer application must be varied based on varying soil conditions across the research block.

Keywords: Spatial variability, soil chemical and physical properties

DEDICATION

I dedicate my mini-dissertaion to my brother (Lebogang Phefadu), father (Andries Phefadu) and grandmother (Francinah Mampuru) for the continued support and encouragement they gave me throughout my academic pursuits.

ACKNOWLEDGEMENTS

The success of this work was only possible due to the cooperation of several people, to which I wish to express my gratitude. To my supervisors, Prof FR Kutu and Dr FMG Vanassche, I appreciate the faith they showed in my work. Their support was without a doubt crucial in my dedication to this study. Sincere thanks to Ms PM Kgopa, Mr MM Masowa, Mr MJ Makgato and Ms RL Ntsoane for their unconditional support and assistance in my project. Furthermore, thanks to Dr A Manyevere, Dr MG Zerizghy, Mr M Mpati and Mr R Tswai (ARC-ISCW) for assisting me with the creation of variability maps. I would also like to express my appreciation to every person who played various roles in making this study successful, especially VLIR-project 6 leaders for their financial support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The characterization of the spatial variability of soil attributes is essential to achieve a better understanding of the complex relations between soil properties (Goovaerts, 1998), and to establish appropriate management practices for soil resources use (Bouma *et al*., 1999). Spatial variability of soil physical and chemical properties within or among agricultural fields is inherent in nature due to geological and pedological soil forming factors, but part of the variability may be induced by tillage and other soil management practices (Iqbal *et al.,* 2005). Thus, an ideal experimental field is an area in which the soil variability has been minimised for a specific crop or soil physical/chemical treatments (Cerri *et al.,* 2004).

Characterizing spatial variation of soil variables can provide important implications in water and nutrient management and fertilizer applications in agricultural production (Saglam *et al.,* 2011). Agricultural sustainability depends to a large extent on improvements in soil properties, especially physical and chemical properties. These soil properties are controlled by many factors, of which the mineral nutrition is by and large the most important (Jat *et al*., 2006). Cerri *et al.* (2004) stated that understanding the distribution and nature of these soil properties in the field is essential in refining agricultural management practices while minimizing environmental damage. Information on the spatial variability of soil properties leads to better management decisions aimed at correcting problems, maintaining productivity, fertility and sustainability of the soils (Özgöz, 2009).

1.2 Problem statement

Soil chemical and physical properties change overtime within agricultural fields, usually depending on soil forming factors, type of land use and soil management practices. The influence of poor soil management remains a major challenge in agriculture for maintaining soil productivity and fertility (Kibblewhite *et al.,* 2008). The experimental farm of the University of Limpopo has been previously, and is currently being used for conducting various experiments centred largely on cereal and legume crops. Cereal crops by their nature are heavy feeders requiring large amount of nutrients, particularly nitrogen, N, (Nsanzabaganwa *et al*., 2014) while legumes are able to fix N into the soil. Such crop evaluation trials are often accompanied by variable fertiliser use that imposes a high degree of nutrients variability on the field. Yet, there is no recent and detailed reliable information about the physical and chemical status of the soils in the research block. At the farm, conventional tillage is practiced and during the planting season the soil is bare (Moshia *et al.,* 2008). There are parts of the research block that are continuously cultivated, while there is a part that has been left bare for some time. Hence, there is a need to find in detail the variability of the soil in the research block. This will enable researchers to follow appropriate soil and crop management practices. Furthermore, information on possible differences in soil chemical and physical properties could help explain eventual anomalies in the results of current and future planned experiments on the field such as the on-going drought resistant crops and food security research project (VLIR project 6).

1.3 Motivation of the study

The characterization of soil for spatial variability of its attributes is the first step for project establishment in the field. Thus understanding the distribution and relationship between soil chemical and physical properties within agricultural fields is important for field trials. The distribution of these soil properties may be spatially variable, resulting in difficulties for maintaining soil productivity and fertility. A previously conducted study was focusing on the influence of parent material (granite and schist) on physical and chemical properties of soils at Syferkuil experimental farm (Maribeng, 2007). Heterogeneity is an inherent quality of soil that characterizes its distribution in a particular area (Junior *et al*., 2006). Therefore, evaluation of soil spatial variability becomes an important issue in agricultural research. The information obtained from this study does not give in depth soil information of the research block. Thus a detailed soil characterization of the research block will allow researchers to follow crop and soil management practices aligned with the soil conditions (Castrignanò *et al.,* 2000), and therefore increasing and sustaining soil productivity and fertility.

1.4 Purpose of the study

1.4.1 Aim

The aim of this study was to investigate the spatial variability of soil physical and chemical properties in the research block at the University of Limpopo Experimental Farm, Syferkuil.

1.4.2 Objectives

The objectives of the study were to:

i. evaluate the spatial distribution of soil physical and chemical characteristics in the research block.

ii. study the correlation between soil physical and chemical characteristics.

iii. identify trends in variability across the research block.

1.5 Hypotheses

i. There are no differences in spatial distribution of soil physical and chemical characteristics in the research block.

ii. There is no correlation between the physical and chemical characteristics.

iii. There are no variability trends across the research block.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil chemical properties in relation to soil productivity

Understanding the soil chemical composition and its variation is essential for utilizing and managing the soils. Soil chemical levels such as total nitrogen, total phosphorus, soil organic carbon, electrical conductivity, and pH are essential in evaluating soil fertility, soil quality, and soil productivity (Bai and Wang, 2011). Furthermore, soil chemical properties play an important role in assessment and advancement of sustainable ecosystem management (Fu *et al.*, 2010). Excess nitrogen and phosphorus may lead to agricultural non-point source pollution and water quality degradation (Vervier *et al.*, 1999). Soils with high electrical conductivity values can affect soil aggregation and structure. Therefore, understanding and utilizing the spatial variability of soil chemical properties can provide a useful foundation for improving soil quality, increasing soil productivity and health, advancing agriculture, and protecting the environment (Bai and Wang, 2011).

Slope position has a large effect on soil chemical properties because it affects runoff, infiltration, soil temperature, erosion, and soil formation (Tsui *et al.*, 2004). Thus, assessment of soil chemical properties variation across a slope within an area is important in environmental modelling and natural resources (e.g. soil) management (Tsui *et al.*, 2004). Numerous researchers have indicated that slope plays an important role in controlling the spatial distribution of soil properties (Wei *et al.*, 2008; Wang *et al.*, 2009). Soil chemical properties are affected by soil amendment and production systems. For example, at the Rodale Institute, long-term legume-based and organic production systems have resulted in an increase in soil organic matter and have reduced nitrate runoff (Drinkwater *et al*., 1998). Soils in organic production systems lost less nitrogen into nearby water systems than did conventional production systems (Liebhardt *et al.*, 1989). The amount of soil nitrogen in fields under conventional production systems has been negatively correlated with soil microbial components, whereas soil nitrogen in fields under organic production was positively correlated with soil microbial components (Gunapala and Scow, 1998).

The availability of micronutrients is particularly sensitive to changes in soil environment. The factors that affect the contents of such micronutrients are organic matter, soil pH, lime content, sand, silt, and clay contents. There is also a correlation among the micronutrients contents and above mentioned properties (Chaudhari *et al.*, 2012). High levels of sodium cause slaking of aggregates, swelling or dispersion of clay particles and this would decrease hydraulic conductivity through reduction of soil aggregate stability and plugging of soil pores by dispersed clay particles (Mace and Amrheim, 2001). Bell and Dell (2008) reported that the deficiency of nutrients has become a major constraint to productivity, stability and sustainability of soils. Results of chemical together with physical tests are quality indicators which provide information about the capacity of soil to supply mineral nutrients. Electrical conductivity is a very quick, simple and inexpensive method to check health of soils (Chaudhari *et al.*, 2012). The value of soil pH is regarded as a good indicator of balance of available nutrients in the soil; as it is also an indicator of plant available nutrients (Kinyangi, 2007). Soil acidity is a result of mineral leaching, decomposition of acidic plant, industrial wastes, acid rains and certain forms of microbiology activity. Alternatively, soils containing high amounts of sodium, potassium, magnesium and calcium are prone to be alkali (Chik and Islam, 2011).

The application of all the needed nutrients through sole chemical fertilizers has a deleterious effect on fertility and productivity status of soil (Jat *et al*., 2006). No single source of nutrients is capable of supplying plant nutrients in adequate and balanced proportion, whereas conjunctive use of the organic and inorganic sources of nutrients helps in sustaining productivity and biological health of soil in one way and meet a part of chemical fertilizer requirements of crops on the other hand (Babu *et al.*, 2007). The sustainable productivity of the soil mainly depends upon its ability to supply essential plant nutrients to the growing plants (Singh *et al.*, 2013).

2.2 Soil physical properties and land management

Spatial variability of soil physical properties in agricultural fields is inherent in nature due to geological and pedological soil forming factors, but some of the variability may be induced by tillage and other management practices. These factors interact with each other across spatial and temporal scales, and are further modified by erosion and deposition processes (Iqbal *et al.*, 2005). Soil physical properties affect the establishment of crops; these properties are influenced by cultivation employed during seedbed preparation, and vary greatly depending upon the intensity of cultivation (Atkinson *et al.,* 2009).

Seedbed preparation has a significant influence on the physical properties of soil especially soil structure. Soil structure affects the ability of the crop to establish by controlling factors such as soil-seed contact, nutrient uptake, root penetration and soil water movement. Crop establishment can be significantly affected by the variability of the soil texture and structure to retain heat and moisture (Atkinson *et al.,* 2009). The clay, silt, and sand content has an influence on a large number of soil properties such as the water-holding capacity and hydraulic properties, the cation exchange capacity, the movement of nitrate and the soil workability, the soil fertility, and hence the productivity. Researchers as well as producers have an interest in characterising texture variability (Heil and Schmidhalter, 2011).

Soil structure is a key factor in the functioning of soil, its ability to support plant and animal life, and moderating environmental quality with particular emphasis on soil carbon sequestration and water quality (Bronick and Lal, 2004). Aggregate stability is used as an indicator of soil structure (Six *et al.,* 2000). Soil structure influences soil water movement and retention, erosion, crusting, nutrient recycling, root penetration and crop yield, which all of these will be affected when structure is destroyed (Bronick and Lal, 2004).

It is well-established that the addition of organic matter improves the physical properties of soil that are desirable for adequate plant growth (Bolvin *et al*., 2009; Ruehlmann and Körschens, 2009). The increase in soil organic carbon reduces bulk density and increases water holding capacity and soil aggregate stability (Herencia *et al*., 2008). However, the effects of organic matter additions on the physical properties of soils depend on climate, soil characteristics, crop management, and the rate and type of organic amendments. Zhang *et al.* (2006) indicated that changes in soil water retention may depend more on the soil type and the initial organic matter content than on the addition of organic matter.

Soils with high bulk density have a smaller volume of pore spaces. Very high bulk density is therefore undesirable for plant growth, since infiltration, aeration and root development are likely to be below optimum. Generally soils with low bulk densities have favourable physical conditions. In sandy loam soils, organic matter content is generally low, the solid particles lie close together and the bulk density is commonly higher than in fine textured soils (Chaudhari *et al*., 2012). Therefore, bulk density is influenced by the amount of organic matter in soils, their texture, constituent minerals and porosity. Knowledge of soil bulk density is essential for soil management, and information about it is important in soil compaction as well as in the planning of modern farming techniques (Chaudhari *et al*., 2013).

Soil colour is an important soil physical property which soil scientists frequently use for the identification and classification of soils. It is a continuous variable that varies across the landscape and it varies with depth. Vertical variation in soil colour is used to distinguish different horizons in a profile and provides an indirect measure of important soil characteristics including drainage, aeration, organic matter content and general fertility (Viscarra Rossel *et al*., 2006).

In agriculture, studies of the effects of land management on soil properties have shown that cultivation generally increases the potential for soil degradation due to the breakdown of soil aggregates and the reduction of soil cohesion, water content and nutrient holding capacity (Iqbal *et al*., 2005; Zhang *et al*., 2011). Conservation agriculture is now widely recognized as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental, and social sustainability (Malecka *et al*., 2011). The basic elements of conservation agriculture are: very little or no soil disturbance, direct drilling into previously untilled soil, crop rotation, and permanent soil cover (Holland, 2004; Derpsch, 2007).

Soil management systems play an important role in sustainable agriculture and environmental quality. Management practices have a greater effect on the direction and degree of changes in soil properties (Kilic *et al*., 2012). Soil tillage systems lead to an increase of soil pH, base saturation, and extractable phosphorus (Paz-Gonzalez *et al*., 2000). Generally most farmers prefer to use one soil and crop management set of practices for the entire field as a homogenous area. Such management creates inefficiencies by over-treating or under-treating portions of a field (Castrignano *et al*., 2000). Addition of appropriate doses of organic matter and lime helps in maintaining better and favourable physical conditions of soils for sustainable farm productivity (Singh *et al*., 2013).

The soil physical properties are also affected by many factors that change vertically with depth, laterally across fields and temporally in response to climate and human activity (Swarowsky *et al*., 2011). Since this variability affects plant growth, nutrient dynamics, and other soil processes, knowledge of the spatial variability of soil physical properties is therefore necessary.

2.3 The influence of soil spatial variability on its management and productivity

Soil variability occurs due to factors acting at several spatial and temporal scales, produced by complex pedological processes (Burrough, 1993), relief and moisture regimes (Rezaei and Gilkes, 2005). However, crop management also alters soil variability (Burgos *et al*., 2006), particularly due to tillage and fertilizing practices (Kilic *et al.,* 2004). Inadequate fertilizer management limits crop yield, results in nutrient mining, and causes loss of soil productivity (Morales *et al*., 2014). The productive capacity of soils within a given catena varies spatially in part as a result of differences in soil properties, landscape location, soil depth, and hydrology (Daniels *et al*., 1987; Rhoton and Lindbo, 1997; Stone *et al*., 1985). Schumacher *et al*. (1999) discovered that the changes in soil productivity reflect a reduction in topsoil depth and root zone depth in the shoulder and back-slope positions, and a corresponding increase in topsoil and root zone depth in the foot-slope and toe-slope positions.

Soil physical and chemical properties are strongly influenced by soil management systems and changes in land use (Hulugalle *et al*., 1997). Inman *et al*. (2005) reported that fields that have a high degree of spatial variability in soil properties could be better managed using site-specific management zones. Demands for more accurate information on spatial distribution of soils have increased with the inclusion of the spatial dependence and scale in ecological models and environmental management systems. This is because the variation at some scales may be much greater than at others (Yemefack *et al*., 2005). When studying and managing several varying factors, as is generally done in crop and soil management, it is important to look not only at which factors vary, but also at whether their variability is independent or linked to another factor (Brouder *et al*., 2001).

The development of site specific farming techniques allows the identification of yield variation and promises to provide the capability of uniquely managing areas with different soil properties (Vanden Heuvel, 1996). Managing spatial variation within the field requires a higher level of management and reduces operational efficiencies (Schumacher *et al*., 1999). Interest in having representative information on soil spatial variability has therefore grown, resulting in the development of new management systems (Godwin and Miller, 2003).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of the study site

This study was conducted at the University of Limpopo Experimental Farm (Syferkuil) in the Mankweng area, Polokwane. The area is located at 23°50’36.86”S and 29°40’54.99”E, 1324 meters above sea level within Limpopo Province and experiences hot summers with an annual rainfall of 350 - 500 mm. The research block in which the study was conducted is used for experiments by students and researchers in plant production and soil science divisions and agricultural research council (ARC) researchers.

3.2 Sampling points selection and digging of the soil profiles

Twelve soil profile pits were dug across the research block. The areas where the profile pits were dug were randomly selected for even distribution across the entire block. The coordinates of each profile pit were measured using a GPS device (Trimble Juno 3D) and the map showing the distribution of the pits across the study location are shown in Table 1 and Figure 1.

Table 1: The GPS coordinates of the soil profile pits in the research block

Profile No.	GPS co-ordinates	
	Latitude	Longitude
1	S23°50.054’	E029°41.529’
2	S23°50.041’	E029°41.515’
3	S23°50.017’	E029°41.488’
4	S23°50.000’	E029°41.468’
5	S23°50.053’	E029°41.398’
6	S23°50.166’	E029°41.469’
7	S23°50.081’	E029°41.507’
8	S23°50.148’	E029°41.533’
9	S23°50.186’	E029°41.544’
10	S23°50.142’	E029°41.590’
11	S23°50.112’	E029°41.622’
12	S23°50.062’	E029°41.548’

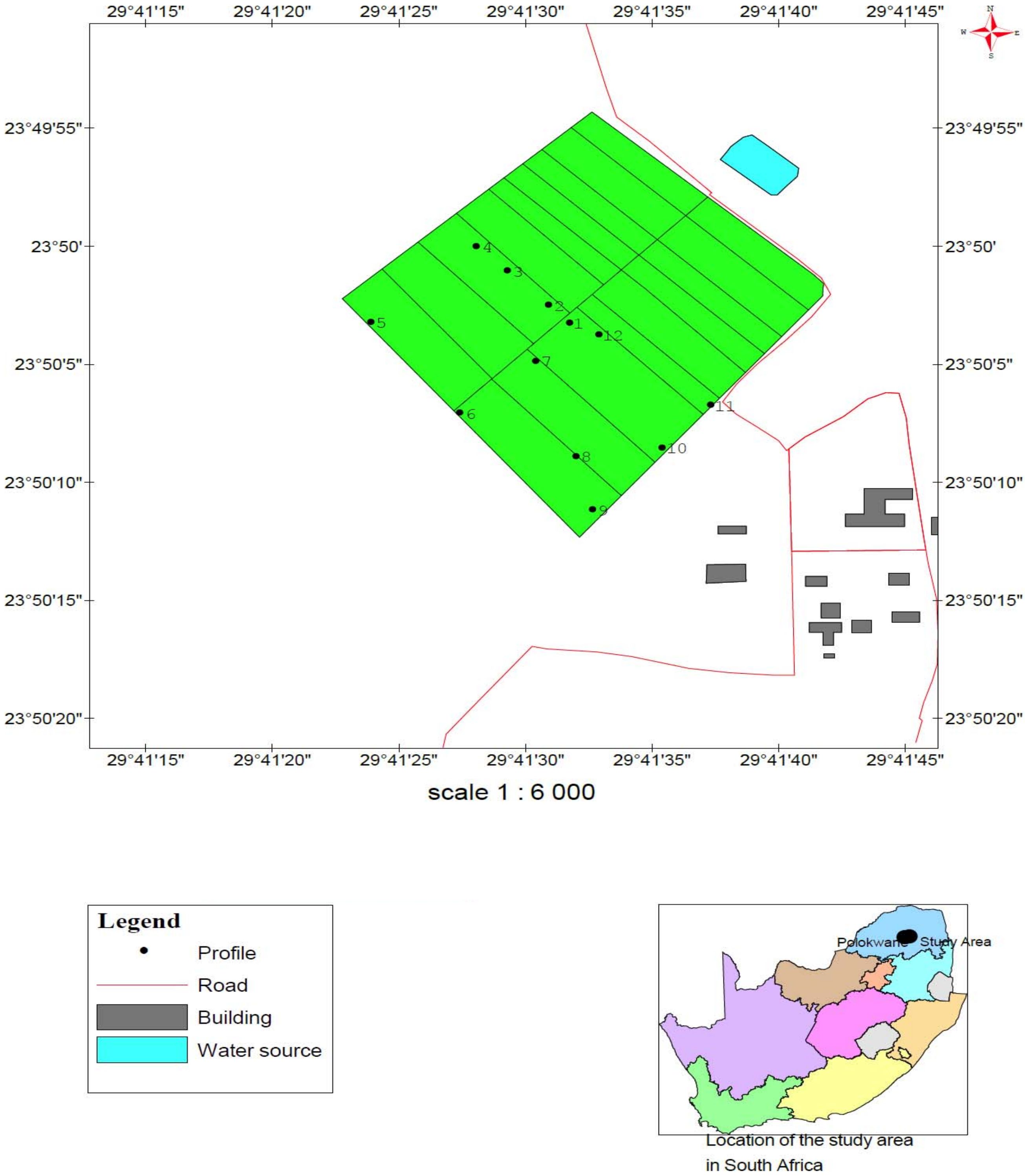

Figure 1: Map of the study location showing the twelve soil profiles that were characterized

3.3 Horizon demarcation, physical parameters characterization and soil sampling

The horizons were demarcated based on soil colour. Soil colour was determined in both moist and dry state using the Munsell soil colour chart, which separates colour into components of hue (relation to red, yellow and blue), value (lightness or darkness) and chroma (paleness or strength) (Schoeneberger *et al.,*1998). Soil structure was characterized based on the soil structure types. Soil samples were collected from each horizon of every soil profile and analysed for selected soil chemical and physical parameters in the University of Limpopo Soil Science laboratory. Some of the physical properties namely: depth, structure and consistency were documented in the field.

3.4 Analyses of physical and chemical properties of soil samples

Soil physical properties namely soil texture and bulk density were determined using the hydrometer method (Bouyoucos, 1962) and the cylindrical core method (Campbell and Henshall, 1991) respectively. Soil chemical properties (EC, pH, OC, P, K, Ca, Mg, Na, Fe, Cu, Zn, Mn and ECEC) were analysed with a specific method: electrical conductivity (EC): a conductivity cell by measuring the electrical resistance of a 1:5 soil: water suspension; pH: soil to water and soil to 1mol dm^{-3} KCl at a ratio of 1:2.5; organic carbon (OC): Walkley-Black chromic acid wet oxidation method; extractable phosphorus (P): using Bray-1 method; extractable cations namely sodium (Na), calcium (Ca) and magnesium (Mg): saturated paste extract method; potassium (K): modified ISFEI method; iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn): Ambic-1 (The Non-Affiliated Soil Analysis Work Committee, 1990). All determinations were carried out at the University of Limpopo Soil Science laboratory.

3.5 Data analyses

The collected data were subjected to classical statistical methods to obtain the minimum, maximum, mean, median, skewness (Shapiro and Wilk, 1965), and standard deviation for each horizon (n = 22). A one way analysis of variance was also performed using Statistix 8.1 to compare each variable across the soil profiles using LSD test at 5%.

3.6 Production of variability maps and semivariograms for the selected measured soil parameters

The soil variability maps and semivariograms based on selected measured parameters were created using ArcMap10.2 software. The raw data were interpolated with an Inverse Distance Weighing (IDW) technique (Zhang *et al.,* 2009) and ordinary kriging methods respectively. Geostatistical data were processed at ARC-ISCW GIS department in Pretoria and University of Limpopo.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Distribution of selected soil physical parameters in the research block

The data revealed that the depth of the profiles ranged from 28 cm to 100 cm (Table 2) and the soils were generally categorized as moderately shallow and deep. The soil depth spatial distribution is controlled by complex interactions of several factors (climate, parent material, and slope), chemical and physical processes (Pelletier and Rasmussen, 2009); thus, soil depth was moderately variable. The shallowest profiles (profile 10 and 11) were on the eastern part of the field. These shallow soil profiles suggest that soils at that side of the experimental block are shallow with limited volume which may restrict growth of deep rooted crops. They also have limited soil volume for water and nutrient storage. Profile 7 was the deepest among all the profiles; it was located at the central part of the field. The soil depth varied from one profile to the other with changes in slope position within the research block. This also contributed to the spatial differences of other soil properties.

The soil colour measured in both dry and moist state ranged from reddish brown to very dark greyish brown depending on the depth of sampling (Table 2). Dark brown soils are thought to contain high levels of nitrogen, have good aeration and drainage, and pose a low erosion risk. Commonly, the opposite is thought of light coloured soils (Viscarra Rossel *et al.,* 2006). Soil colours with hues between red and yellow are predominant in soil. This is possibly as a result of different forms and concentrations of iron (Fe) minerals (Torrent *et al.,* 1983). In well aerated soils ferric (Fe^{+3}) iron compounds are responsible for the brown, yellow and red soil colours. When iron is reduced to ferrous (Fe^{+2}) form it becomes mobile and can be removed from certain areas of the soil (United States Department of Agriculture-NCRS, 2014). When the iron is removed a gray colour remains or the reduced iron colour persists in shades of green or blue (United States Department of Agriculture-NCRS**,** 2014). Thus, the variation in soil colour might have been influenced by organic materials, the presence of iron oxides in the soil and the nature of parent material (Torrent *et al*., 1983). The variations were noticed across the landscape and along the profiles. The dark colour indicated the presence of organic material while the red and yellow colours were the evidence of oxidised iron (Schwertmann, 1993). Vertical soil colour variation was used to distinguish horizons. Soil colour can be used as an indirect measure of general fertility and to qualitatively describe the moisture status of a soil with dry soils being generally lighter in colour than moist or wet soils (Viscarra Rossel *et al.,* 2006).

There was soil structure variation among the twelve soil profiles. The soil structure was predominantly blocky in eleven profiles for both surface and subsurface soil, only profile two showed structure variation with a granular structure in the topsoil (RBP2T) and a platy structure in the subsoil soil (RBP2S) (Table 2). The blocky structure might have resulted from shrinking and swelling of clay minerals in the soil (Horn and Smucker, 2005). The soils were characterized as well-structured soils due to the blocky shape of the aggregates. These kinds of soils allow good water and air movement, which helps plant root distribution. Good soil structure is vital, as it can affect the availability of air and water for plant growth. Soil structure exerts important influences on the edaphic conditions and the environment (Horn and Smucker, 2005). Therefore, favourable soil structure is important for improving soil fertility, increasing agronomic productivity, enhancing porosity and decreasing erodibility (Bronick and Lal, 2004). Poor soil structure can greatly reduce plant growth, making it difficult for plants to obtain water, air and nutrients. Soil structure affects the soil's ability to withstand cultivation and compaction by machinery. A sandy soil is weakly structured because the sand grains are weakly bonded together. Soil with very heavy dispersive clay which sets hard into large sheets when dry has a massive structure (Department of Environment and Primary Industries, 2003).

The consistency of the soil determined dry was mainly firm and friable (Table 2). Soil consistency is determined by soil texture, bulk density and soil structure. Soils with firm and friable consistency can be regarded as easily workable soils depending on the moisture content (Buol *et al*., 2011). There was a moderate textural variation across and within the profiles. The proportion of sand, silt and clay particles of the twenty two samples fall in the range 61-87%, 1-15% and 7-27%, respectively; and are broadly categorised as sandy loam, loamy sand and sandy clay loam (Table 3). The sand and clay content has an influence on a large number of soil properties such as water holding capacity, cation exchange capacity, soil workability and general soil fertility and productivity (Heil and Schmidhalter, 2011). This type of

Table 2: Physical parameters of the twelve soil profiles dug across the research block within the experimental farm

Profile ID	Profile depth (cm)	Horizon thickness (cm)	Soil colour (dry)	Soil colour (moist)	Soil structure	Soil consistence (dry)
RBP1T	80	0-48	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP1S		48-80	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP2T	60	0-22	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Granular	Friable
RBP2S		22-60	7.5YR 6/8 (Reddish yellow)	7.5YR 4/6 (Strong brown)	Platy	Extremely firm
RBP3T	61	0-34	7.5YR 4/4 (Dark brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP3S		34-61	7.5YR 5/6 (Strong brown)	7.5YR 4/4 (Dark brown)	Blocky	Friable
RBP4T	79	0-37	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Friable
RBP4S		37-79	5YR 5/8 (Yellowish red)	5YR 4/4 (Reddish brown)	Blocky	Friable
RBP5T	80	0-24	10YR 3/2 (Very dark greyish brown)	10YR 2/2 (Very dark brown)	Blocky	Firm
RBP5S		24-80	10YR 5/2 (Greyish brown)	10YR 3/3 (Dark brown)	Blocky	Friable
RBP6T	85	0-32	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP6S		32-85	5YR 5/4 (Reddish brown)	5YR 4/4 (Reddish brown)	Blocky	Friable
RBP7T	100	0-46	5YR 4/3 (Reddish brown)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP7S		46-100	7.5YR 5/4 (Brown)	7.5YR 4/3 (Dark brown)	Blocky	Friable
RBP8T	98	0-30	7.5YR 4/4 (Dark brown)	7.5YR 3/3 (Dark brown)	Blocky	Friable
RBP8S		30-98	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Friable
RBP9T	45	0-20	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP9S		20-45	5YR 5/8 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Firm
RBP10T	30	0-30	7.5YR 4/6 (Strong brown)	7.5YR 3/4 (Dark brown)	Blocky	Firm
RBP11T	28	0-28	7.5YR 4/6 (Strong brown)	7.5YR 3/3 (Dark brown)	Blocky	Firm
RBP12T	94	0-30	5YR 4/4 (Reddish brown)	5YR 3/3 (Dark reddish brown)	Blocky	Firm
RBP12S		30-94	5YR 4/6 (Yellowish red)	5YR 3/4 (Dark reddish brown)	Blocky	Friable

RBP1T = Research Block Profile 1 Topsoil, RBP1S=Research Block Profile 1 Subsoil

soil textures is good for agricultural purposes particularly crop production. Clay content in soils influences the water holding capacity and water retention properties in soils (Debnath *et al.,* 2012). Soil texture plays a key role in carbon storage and strongly influences nutrient retention and availability (Najmadeen *et al.*, 2010).

The bulk density values ranged between 1.20 g/cm^3 and 1.80 g/cm^3 in the research block (Table 3). A normal range of bulk densities for clay is 0.90 to 1.40 g/cm^3 and a normal range for sand is 1.40 to 1.90 g/cm^3 with potential root restriction occurring at ≥ 1.40 g/cm^3 for clay and ≥ 1.60 g/cm^3 for sand (Lal, 2006). The specific bulk density that will adversely affect plant production and development depends on several factors including the parent material, soil texture, the crop being grown and current and previous management (Logsdon and Karlen, 2004). The variation was noticed across and down the profile; and it also increased with the increase in percentage of sand particles, but the variation was not significant.

Chaudhari *et al*. (2013) reported that the sand content has a bigger effect on soil bulk density than other soil properties. The high bulk density values obtained in the research block indicated that there is a problem of soil compaction in some parts of the field. Soil compaction results in high bulk density; which in turn causes root growth restriction, poor air and water movement in the soil. Soil bulk density also increases with increasing soil compaction and is therefore, considered as an indicator of soil compaction (Afzalinia *et al*., 2011). Thus, very high bulk density is undesirable for plant growth, since infiltration, aeration and root development are likely to be below optimum (Chaudhari *et al*., 2013).

According to Logsdon and Karlen (2004), higher amounts of organic carbon may result in smaller bulk densities in some cases because it has a lower particle density than mineral particles. Soils with high clay content tend to have lower bulk densities than sandy soils. Sandy soils have relatively higher bulk density because the total pore space in sands is less than that of silt and clay soils. High bulk density causes restrictions to root growth, and poor movement of air and water through the soil (United States Department of Agriculture, NCRS, 2008). Generally soils with low bulk densities have favourable physical conditions (Chaudhari *et al*., 2012).

Table 3: Texture and bulk density variations across the twelve soil profiles

Profile ID	% Sand	% Silt	% Clay	Texture class	BD g/cm^3
RBP1T	71	12	17	Sandy loam	1.48
RBP1S	74	12	14	Sandy loam	1.35
RBP2T	71	15	14	Sandy loam	1.47
RBP2S	84	9	7	Loamy sand	1.27
RBP3T	67	9	24	Sandy clay loam	1.55
RBP3S	61	12	27	Sandy clay loam	1.58
RBP4T	81	2	17	Sandy loam	1.75
RBP4S	67	9	24	Sandy clay loam	1.54
RBP5T	77	2	21	Sandy clay loam	1.74
RBP5S	84	9	7	Loamy sand	1.50
RBP6T	74	2	24	Sandy clay loam	1.56
RBP6S	80	9	11	Loamy sand	1.46
RBP7T	77	2	21	Sandy clay loam	1.78
RBP7S	74	9	17	Sandy loam	1.57
RBP8T	84	2	14	Sandy loam	1.69
RBP8S	68	7	25	Sandy clay loam	1.57
RBP9T	87	2	11	Loamy sand	1.65
RBP9S	84	2	14	Sandy loam	1.80
RBP10T	84	1	15	Loamy sand	1.78
RBP11T	87	2	11	Loamy sand	1.72
RBP12T	87	2	11	Loamy sand	1.72
RBP12S	74	2	24	Sandy clay loam	1.60
CV %	10	75	36		9

RBP1T= Research block profile 1 topsoil, RBP1S=Research block profile 1 subsoil, BD=bulk density
CV=Coefficient of variation

Soil physical properties play a significant role in determining soil suitability for crop production. Thus, characteristics such as tillage practices, moisture storage capacity and its availability to plants, drainage, ease of penetration by roots, aeration, nutrient retention and availability are all intimately connected with the soil physical properties (Debnath *et al.,* 2012).

4.2 Distribution of selected soil chemical parameters in the research block

The data revealed that most of the soil samples were moderately alkaline. The pH_W (6.85 – 8.55) values showed that twenty samples were slightly alkaline and two were slightly acidic; while on the other hand the pH_{KCl} (5.34 – 7.49) values showed that sixteen soil samples were acidic and six were slightly alkaline (Table 4). The pH varied from slightly acidic to slightly alkaline. Only two topsoil samples from profile 5 and 9 on the western and southern parts of the block were slightly acidic with pH values of 6.92 and 6.85 respectively. Soil acidity is formed due to mineral leaching, acid rains and certain form of microbiology activity. There was a significant ($p<0.05$) variation in pH_W and pH_{KCl} values across and down the profiles, pH_W was higher (0.69 to 1.75 units) than pH_{KCl}. Both pH_W and pH_{KCl} had the same variation pattern; most values were lower in the surface soil than in the subsurface soil.

The average pH_W and pH_{KCl} were slightly alkaline and slightly acidic respectively (Table 4). Soil pH was generally categorised as slightly alkaline considering the pH_W level which is the measure of the actual soil pH. According to Chik and Islam (2011) soils containing high amounts of calcium, potassium, magnesium and calcium are likely to be alkaline. Soils (profiles 5, 6 & 9) were close to neutral level. The alkaline soil pH might be a result of the presence of base cations in the soil, type of crops grown and irrigation water. Kilic *et al.* (2012) reported that soil pH in cultivated lands is greater due to the high salt concentration of the irrigation water. The balance of soil pH is vital in maintaining optimum nutrient availability in the soil. Soil pH has an important influence on soil nutrient availability, solubility of toxic nutrient elements and cation exchange capacity (Arain *et al.,* 2000). Chaudhari *et al.* (2012) stated that some nutrients become unavailable if the soil pH is extremely acidic or alkaline. This is due to the fact that they become insoluble at specific pH levels.

The EC values (topsoil 34.57 - 117 mS/cm; subsoil 49.43 - 229.67 mS/cm) showed that the soils in the research block are not saline (Table 4). There was variability across and along the profiles but it was not significant. According to Molin and Faulin (2012) electrical conductivity varies with variations in soil salinity, clay content and cation exchange capacity, clay minerals, pore size and distribution, organic matter and temperature. Waskom *et al.* (2014) established a general classification for salt affected soils which shows that saline soils have EC levels of greater than 2 dS/m

(2000 mS/cm). The EC was predominantly lower in the surface than in the subsurface.

High EC values are directly proportional to salt levels in the soil while low EC values show that the soil is not affected by salts. The high amount of salts in the soil may be a result of the salts contained in the irrigation water remaining in the soil as the pure water evaporates to the atmosphere. Thus, this can also cause specific iron toxicity or disturb soil nutritional balance (Corwin and Lesch, 2003). Excessive amounts of salt accumulations occur in poorly drained soils subjected to high evapotranspiration (Wang *et al.*, 2008). The electrical conductivity in soil is caused by ionic conduction in soil water coupled with conduction through the soil solids (Vaugham *et al*., 1995). Guler *et al.* (2014) reported that type and amount of fertilizers and quality of irrigation water may have an influence on spatial structure of electrical conductivity.

The organic carbon content ranged from 0.27 to 1.04% (Table 4). The soils in the research block have a low soil organic carbon content. There was no significant variation in the distribution of organic carbon. The amount of organic carbon in the soil depends on soil texture, climate and the current land use and/or management practices. According to West and Post (2002), changes in agricultural management can increase or decrease soil organic carbon. Soil organic carbon content in sandy soil is less than 1% (Milne, 2012). There was a slight variation in distribution of organic carbon across the field. This variation in the amount of organic carbon is probably due to the differences in crop residue decomposition rate (Tsui *et al*., 2004). Mzuku *et al.* (2005) reported that higher organic matter content will likely contributes to increased aggregation and therefore increased soil aggregate stability. Soil erosion and leaching of dissolved carbon into groundwater can lead to carbon loss. When carbon inputs and outputs are in balance with one another, there is no net change in soil organic carbon levels. The processes of erosion and deposition act to redistribute soil carbon according to the topography of the landscape, with the low-lying areas often enjoying increased soil organic carbon relative to the upslope positions (Ontl and Schulte, 2012).

Table 4: Selected chemical parameters of the twelve soil profiles dug across the research block within the experimental farm

Profile ID	pH_W	pH_{KCl}	EC mS/cm	Bray-1 P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg	ECEC meq/ 100 g	OC %
RBP1T	7.52	6.78	56.23	2	70	810	508	103	8.56	1.64	0.54	33	8.88	0.30
RBP1S	8.38	6.96	94.33	1	70	913	710	173	16	1.60	0.52	23	11.36	0.35
RBP2T	8.04	7.21	117.00	7	173	1068	668	88	14	1.84	1.08	39	11.69	0.38
RBP2S	8.49	7.25	139.23	1	60	1360	890	178	12	1.88	0.72	31	15.08	0.80
RBP3T	7.86	6.20	88.83	12	238	788	505	60	11	1.80	1.64	47	8.98	0.88
RBP3S	7.44	6.15	74.20	1	70	1055	683	115	17	1.84	0.52	32	11.60	0.83
RBP4T	7.23	6.39	66.13	14	228	718	433	40	23	1.76	1.80	42	7.93	0.49
RBP4S	7.99	6.10	80.30	1	98	958	708	128	18	1.56	0.48	26	11.45	0.35
RBP5T	6.92	6.23	70.20	9	150	1053	538	20	17	1.72	1.44	33	10.18	0.88
RBP5S	8.50	7.49	229.67	1	70	1910	920	138	13	1.56	0.76	27	17.93	0.75
RBP6T	7.08	5.95	44.43	15	298	805	420	23	15	1.80	0.72	23	8.36	0.71
RBP6S	8.18	7.22	87.67	3	150	1050	620	68	20	1.92	0.24	21	11.05	0.65
RBP7T	7.32	6.54	73.30	10	128	803	495	25	12	1.44	1.24	29	8.54	0.73
RBP7S	8.55	7.36	163.30	1	73	853	910	200	17	1.68	0.36	20	12.84	0.67
RBP8T	7.90	6.54	42.93	17	90	613	373	20	10	1.48	1.28	35	6.47	0.58
RBP8S	7.85	6.45	75.90	1	33	645	443	93	11	1.92	0.40	20	7.38	0.49
RBP9T	6.85	5.34	34.57	16	88	385	203	15	8.12	1.36	1.88	28	3.89	0.57
RBP9S	7.17	6.09	49.43	2	33	493	308	10	4.88	1.72	0.44	16	5.14	0.66
RBP10T	7.52	6.39	40.27	15	70	393	265	8	9.16	1.16	1.68	31	4.37	0.27
RBP11T	7.91	6.90	59.37	19	78	600	390	40	13	1.28	1.60	26	6.60	0.35
RBP12T	8.10	7.00	50.73	18	93	563	338	30	9.52	1.40	1.72	30	5.98	0.83
RBP12S	8.05	6.30	51.60	2	43	655	465	95	13	1.76	0.44	19	7.64	1.04

RBP1T= Research block profile 1 topsoil, RBP1S=Research block profile 1 subsoi, EC = electrical conductivity, OC= organic carbon, ECEC= effective cation exchange capacity

Bray-1 P, EC, K, Mg, Ca, Mn, Na, Zn and ECEC differed significantly ($p<0.05$) with depth while percentage K, Mg, Ca, Mn, OC and ECEC differed significantly ($p<0.05$) across soil profiles (Tables 4 and 5). Variations in soil properties can be expressed by dividing the coefficient of variation (CV) into different ranges, for example, least (<15%), moderate (15 - 35%) and most (>35%) (Wilding, 1985). The coefficient of variation values of 21.7 - 45.8% were obtained for electrical conductivity, Bray-1 P, exchangeable K, Ca and Na as well as extractable Fe and Zn (Table 5). The EC, Bray-1 P, K and Na were the most variable measured soil chemical parameters with CV above 35%. Similarly, OC, Ca, Mg, Fe, Zn and ECEC were moderately variable with CV between 15 and 35%; and pH_W, pH_{KCl}, Cu and Mn were least variable with CV less than 15% (Table 5). Majority of the chemical parameters in Table 5 were slightly skewed with a coefficient of skewness greater or less than 0.5. The variables that were normally distributed included pH_W and pH_{KCl}, organic carbon, available phosphorus (Bray-1 P), extractable Fe, Cu and Zn with a coefficient of skewness <0.5, while EC, ECEC, extractable Mn, exchangeable Ca, Mg, Na and K were not normally distributed with a coefficient of skewness >0.5 (Table 5).

The mean values for pH (water & KCl), EC, Ca, Mg, Na, Fe, Cu, ECEC and OC were greater in the subsurface soil than in the surface soil while mean values for Bray-1 P, K, Zn and Mn were greater in the surface soil (Tables 6 and 7). This indicated that there was variability in the distribution of the chemical parameters across different soil depths. The standard error mean ranged from 0.065 to 63.266 in the surface soil (Table 5) and 0.0451 to 128.89 in the subsurface soil (Table 7) across the profiles.

Table 5: Summary of statistical analysis of measured chemical parameters of soil samples (n=22) across the twelve soil profiles.

Parameter	Minimum	Maximum	Mean	Median	Skewness	CV%
pH_W	6.85	8.55	7.77	7.88	-0.213	5.8
pH_{KCl}	5.34	7.49	6.58	6.49	-0.145	6.4
EC (mS/cm)	34.57	229.67	81.35	71.75	1.946	45.6
OC%	0.27	1.04	0.62	0.65	-0.028	19.9
Bray-1 P (mg/kg)	1	19	8	5	0.395	41.7
Exch. K (mg/kg)	33	298	109	83	1.393	39.6
Exch. Ca (mg/kg)	385	1910	841	804	1.487	21.7
Exch. Mg (mg/kg)	203	920	536	500	0.497	15.4
Exch. Na (mg/kg)	8	200	76	64	0.677	45.8
Extr. Fe (mg/kg)	4.88	23	13.28	13	0.315	26.2
Extr. Cu (mg/kg)	1.16	1.92	1.64	1.7	-0.665	9.7
Extr. Zn (mg/kg)	0.24	1.88	0.98	0.74	0.339	33.6
Extr. Mn (mg/kg)	16	47	29	29	0.555	12.0
ECEC (meq/100g)	3.89	17.93	9.24	8.71	0.670	15.7

pH_W=Active acidity, pH_{KCl}=Reserve acidity, EC=Electrical conductivity, Bray-1 P= available phosphorus, K=potassium, Ca=Calcium, Mg=Magnesium, Na=Sodium, Fe=Iron, Cu=Copper, Zn=Zinc, Mn=Manganese, OC=Organic carbon, ECEC=Effective cation exchange capacity and CV=percent coefficient of variation

The pH, Bray-1 P, Ca, Mg, Cu, Zn, ECEC and OC were normally distributed in the surface soil whereas EC, K, Na, Fe and Mn were not normally distributed. The skewness was positive (0.01 to 1.226) for EC, K, Ca, Na, Fe, Mn and OC, but negative (-0.012 to -0.7856) for pH, Bray-1 P, Mg, Cu, Zn and ECEC (Table 6). In the subsurface soil pH, Mg, Na, Fe, Cu, Zn, Mn, ECEC and OC were normally distributed while EC, Bray-1 P, K and Ca were not normally distributed. The skewness was positive (0.0003 to 1.3979) for pH_{KCl}, EC, Bray-1 P, K, Ca, Zn, Mn, ECEC and OC, but negative (-0.057 to -0.773) for pH_W, Mg, Na, Fe and Cu (Table 6). The negative skewness indicates that the value of the mean and median is less than the value of the mode which means most of the data are distributed to the left. On the other hand positive skewness shows the mean and median is greater than the mode which means most of the data are distributed to the right.

Table 6: Descriptive Statistics for surface soil depth across the twelve soil profiles

Profile ID	pH_W	pH_{KCl}	EC mS/cm	Bray-1 P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg	ECEC meq/100g	OC %
RBP1	7.52	6.78	56.23	2	70	810	508	103	8.56	1.64	0.54	33	8.88	0.30
RBP2	8.04	7.21	117.00	7	173	1068	668	88	14	1.84	1.08	39	11.69	0.38
RBP3	7.86	6.20	88.83	12	238	788	505	60	11	1.80	1.64	47	8.98	0.88
RBP4	7.23	6.39	66.13	14	228	718	433	40	23	1.76	1.80	42	7.93	0.49
RBP5	6.92	6.23	70.20	9	150	1053	538	20	17	1.72	1.44	33	10.18	0.88
RBP6	7.08	5.95	44.43	15	298	805	420	23	15	1.80	0.72	23	8.36	0.71
RBP7	7.32	6.54	73.30	10	128	803	495	25	12	1.44	1.24	29	8.54	0.73
RBP8	7.90	6.54	42.93	17	90	613	373	20	10	1.48	1.28	35	6.47	0.58
RBP9	6.85	5.34	34.57	16	88	385	203	15	8.12	1.36	1.88	28	3.89	0.57
RBP10	7.52	6.39	40.27	15	70	393	265	8	9.16	1.16	1.68	31	4.37	0.27
RBP11	7.91	6.90	59.37	19	78	600	390	40	13	1.28	1.60	26	6.60	0.35
RBP12	8.10	7.00	50.73	18	93	563	338	30	9.52	1.40	1.72	30	5.98	0.83
Mean	7.52	6.46	62	13	142	717	428	39	12.53	1.56	1.39	33	7.66	0.58
SE Mean	0.128	0.146	6.754	1.450	22.131	63.266	36.553	8.586	1.239	0.067	0.124	1.985	0.660	0.065
Skewness	-0.17	-0.61	1.059	-0.787	0.8261	0.0661	-0.012	1.1347	1.226	-0.246	-0.7856	0.6223	-0.0752	0.01

RBP=Research block profile, EC=electrical conductivity, OC= organic carbon, ECEC=effective cation exchange capacity

Table 7: Descriptive Statistics for sub-surface soil depth across the ten soil profiles

Profile ID	pH_W	pH_{KCl}	EC mS/cm	Bray-1 P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg	ECEC meq/100g	OC %
RBP1	8.38	6.96	94.33	1	70	913	710	173	16	1.60	0.52	23	11.36	0.35
RBP2	8.49	7.25	139.23	1	60	1360	890	178	12	1.88	0.72	31	15.08	0.80
RBP3	7.44	6.15	74.20	1	70	1055	683	115	17	1.84	0.52	32	11.60	0.83
RBP4	7.99	6.10	80.30	1	98	958	708	128	18	1.56	0.48	26	11.45	0.35
RBP5	8.50	7.49	229.67	1	70	1910	920	138	13	1.56	0.76	27	17.93	0.75
RBP6	8.18	7.22	87.67	3	150	1050	620	68	20	1.92	0.24	21	11.05	0.65
RBP7	8.55	7.36	163.30	1	73	853	910	200	17	1.68	0.36	20	12.84	0.67
RBP8	7.85	6.45	75.90	1	33	645	443	93	11	1.92	0.40	20	7.38	0.49
RBP9	7.17	6.09	49.43	2	33	493	308	10	4.88	1.72	0.44	16	5.14	0.66
RBT12	8.05	6.30	51.60	2	43	655	465	95	13	1.76	0.44	19	7.64	1.04
Mean	8.06	6.74	104.56	1.4	70	989.200	665.700	119.800	14.188	1.744	0.488	23.500	11.147	0.66
SE mean	0.1476	0.1809	17.91	0.2211	10.934	128.89	66.552	17.995	1.3817	0.0451	0.0495	1.6816	1.1892	0.0685
Skewness	-0.7325	0.0556	1.1698	1.3979	1.1673	1.0879	-0.283	-0.399	-0.773	-0.057	0.4415	0.3739	0.1422	0.0003

RBP=Research block profile, EC=electrical conductivity, OC= organic carbon, ECEC=effective cation exchange capacity

The availability of Na, K, Na and Mg decreases with the decrease in pH below 5.5 - 6.5 (Baruah *et al.,* 2011). Nutrient availability to plants depends on the concentration, content and activity of each nutrient in the soil. Thus, plant availability of soil Na, Ca, K and Mg is related to the cation activity ratios in the soil solution (Mayland and Wilkinson, 1989). According to Baruah *et al.* (2011), successful crop production demands optimum use of plant nutrients in addition to other management practices in soil. Although Na, Ca, K and Mg are not equally important for plant nutrition, all are necessary for plant growth and they are mainly responsible for maintaining acid-base equilibrium in the soil. The availability of Mg depends on the activity or proportion of Mg relative to soluble and exchangeable amounts of K, Ca, Na, Al and Mn (Mayland and Wilkinson, 1989).

Chu and Johnson (1985) stated that the source of magnesium used by plants is the soil, therefore, over the growing season crops take up magnesium from exchangeable sites or soil solution. In most soils Mg in easily available forms accounts only for a small portion (<10%) of the total soil magnesium. The exchangeable magnesium contained in soil is related to the clay minerals present in the soil (Mayland and Wilkinson, 1989). The principal source of available potassium in soils is its concentration in the soil solution, which could be refreshed by cation exchange with adsorbed potassium ions and which is also affected by content of strongly bounded and non-exchangeable, which are both described as fixed potassium (Jakovljevic *et al.,* 2003). Haby *et al*. (1990) indicated that of all the basic cations found in soils (K, Ca, Mg and Na), potassium is the most important in plant nutrition and it is occasionally found in plants in higher percentages than nitrogen. Exchangeable sodium in the soil and at exchange sites contribute to repulsive charges that disperse clay particles (Bronick and Lal, 2004).

As the size of Na^+ is smaller, rate of adsorption of sodium on soil surfaces and substitution on adsorption sites in soil by other cations (Ca and Mg) increases, hence soil become hard, compact and impermeable to water penetration (Baruah *et al*., 2011). Calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations improve soil structure through cationic bridging with clay particles and soil organic carbon (Bronick and Lal, 2004). Soil pH, organic carbon, available P, exchangeable Ca, sum of bases and effective cation exchange capacity significantly differ with the land-use systems (Agoume and

Birang, 2009). Phosphorus (P) availability in the soil is one of the most limiting factors for plant growth and productivity in natural and agricultural ecosystems (Lynch and Deikman, 1998). Soil phosphorus is most available for plant use at pH values of 6 to 7. When pH is less than 6, plant available phosphorus becomes increasingly tied up in aluminium phosphates. As soils become more acidic (pH below 5), phosphorus is fixed in iron phosphates. When pH values exceed 7.3, phosphorus is increasingly made unavailable by fixation in calcium phosphates (Mississippi Agricultural and Forestry experiment station, 2010). The complex chemistry and spatial variability of phosphorus in soils make direct identification of phosphorus compounds and assessment of plant availability difficult (Pierzynski *et al.,* 1990). The distribution of Zn, Fe, Cu and Mn may differ among the profiles developed on different parent materials and landforms (Verma *et al.,* 2005). The availability of these micronutrients is influenced by their distribution within the soil profile and other soil characteristics (Singh *et al.,* 1989). The solubility and plant-availability of Zn, Fe, Cu and Mn in the soil generally decreases with increasing pH due to adsorption-precipitation reactions. Uptake of micronutrient is affected by the presence of major nutrients due to either negative or positive interactions (Fageria, 2001).

Brady and Weil (2005) reported that Fe and Mn are common in silicate minerals such as biotite and horneblende. Zinc may also replace some of the major constituents of silicate minerals including clays and be found therein, while Cu and Mn are often tightly held by organic matter. It is well known that the optimum plant growth and crop yield depends not only on the total quantity of nutrients present in the soil at a particular time but also on their availability which in turn is controlled by physico-chemical properties such as soil texture, organic carbon, cation exchange capacity, pH and electrical conductivity of soil (Bell and Dell, 2008). Chhabra *et al.* (1996) found that available manganese and iron decreased with soil pH and available copper increased with clay and organic carbon content and available Iron decreased with increasing sand content. The availability of micronutrients is particularly sensitive to changes in soil environment (Chaudhari *et al.*, 2012). There is a correlation among the soil chemical properties which leads to their variation as they interact across the landscape.

4.3 Spatial variability maps of measured soil physical and chemical parameters

The variability map shows that the soils are deeper in the central part of the field towards the western part and shallowest in the eastern part (Figure 2). There is no great depth variation among the profiles except for profile ten and eleven which tended to be shallower than the rest.

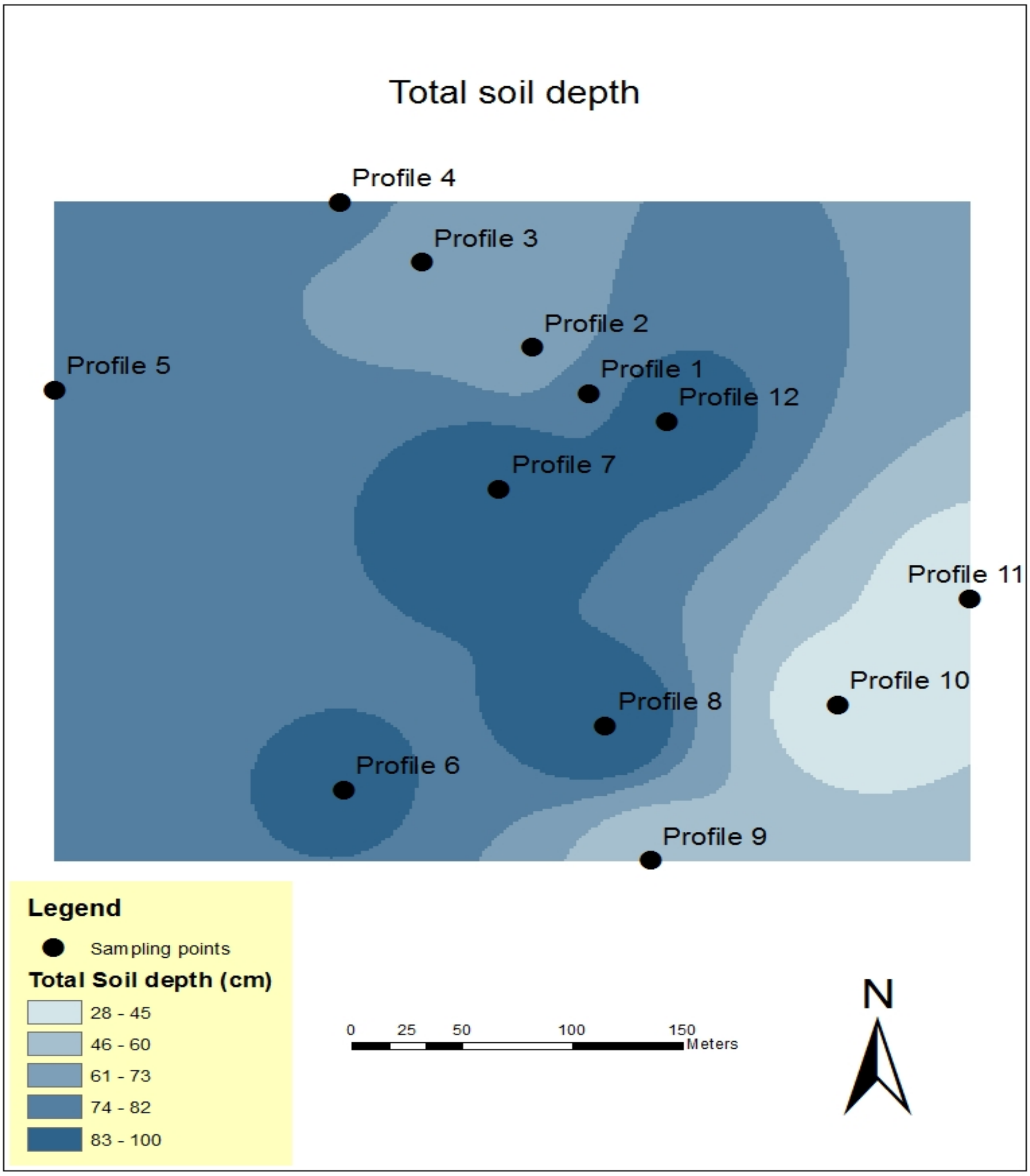

Figure 2: Spatial variability map of total soil depth

The spatial variability map indicates that topsoil horizons with high sand content were found in the south eastern part of the field while those with a lower sand content were in the northern part (Figure 3). Subsoil horizons with high sand content were found in the north, west and southern parts of the field while those with a low sand content were found in the north western and southern parts (Figure 4).

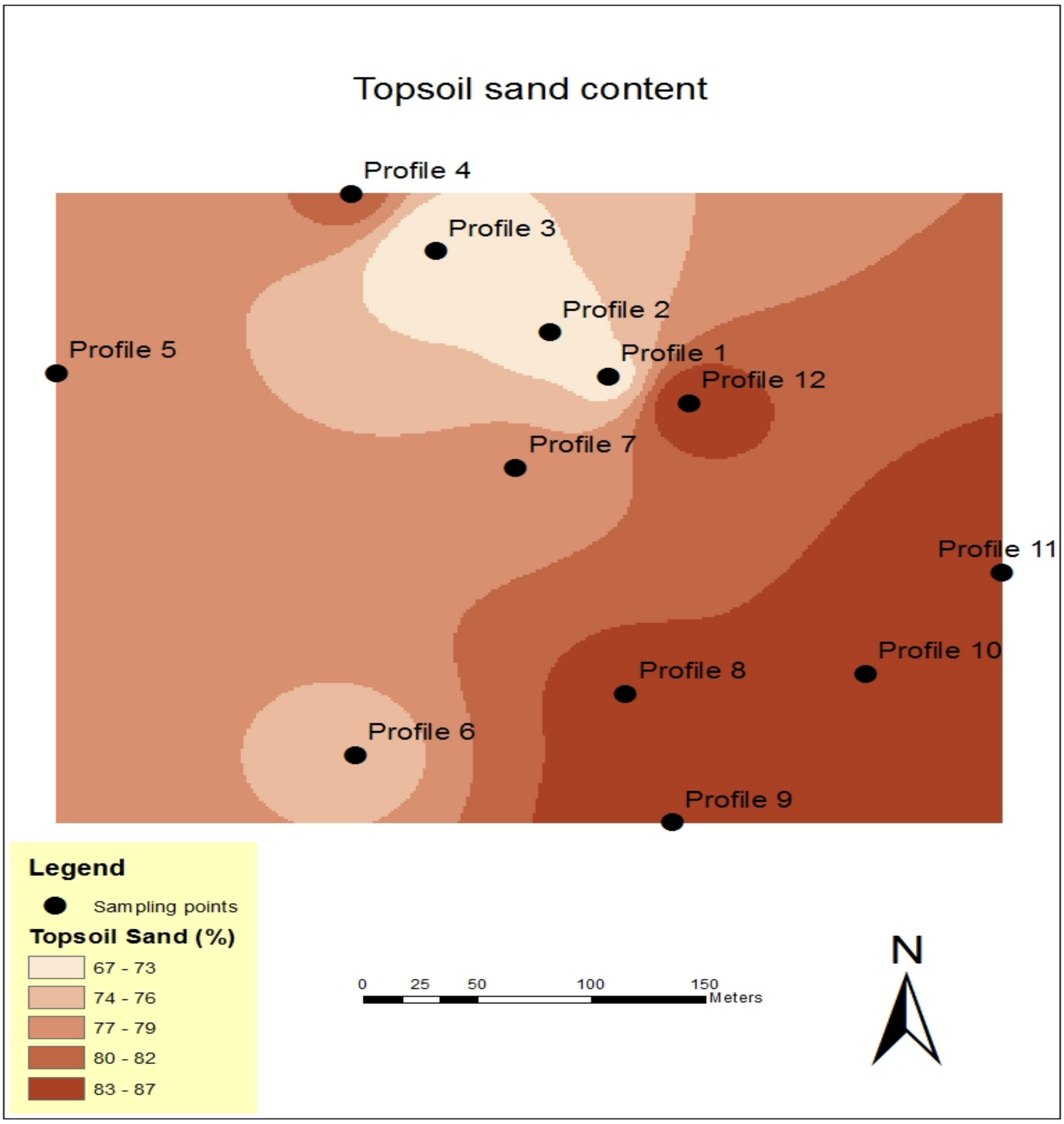

Figure 3: Spatial variability map of topsoil sand content

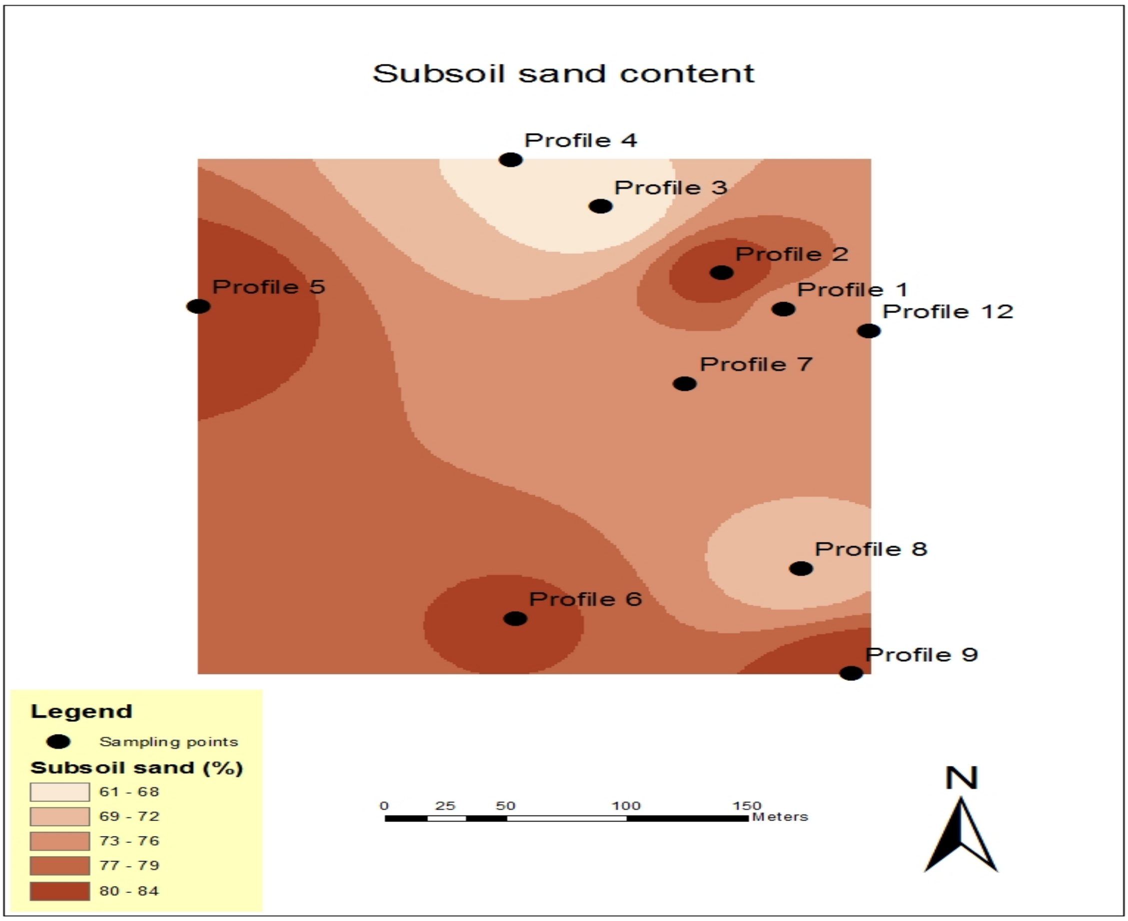

Figure 4: Spatial variability map of subsoil sand content

The clay content of the topsoil horizons was found to be high in the north and western parts of the field and low in the south eastern part of the field (Figure 5), whereas subsoil horizons with high clay content were found in the north and south eastern parts of the field and those with low clay content in the north and south western parts (Figure 6). The maps showed that there is a distinct texture distribution pattern of sand and clay between the topsoil and subsoil horizons. Soils with high bulk density in the topsoil horizons were found in the south eastern and north western part of the field, whereas low bulk density soils were found in the northern and south western parts of the field (Figure 7). In the subsoil horizons soils with high bulk density were found in the southern part of the field, while the bulk density of the other parts of the field which showed to be low was fairly distributed mainly on the north western part of the field (Figure 8). The maps indicated that the topsoil horizons have high bulk densities and the subsoil horizons low bulk densities.

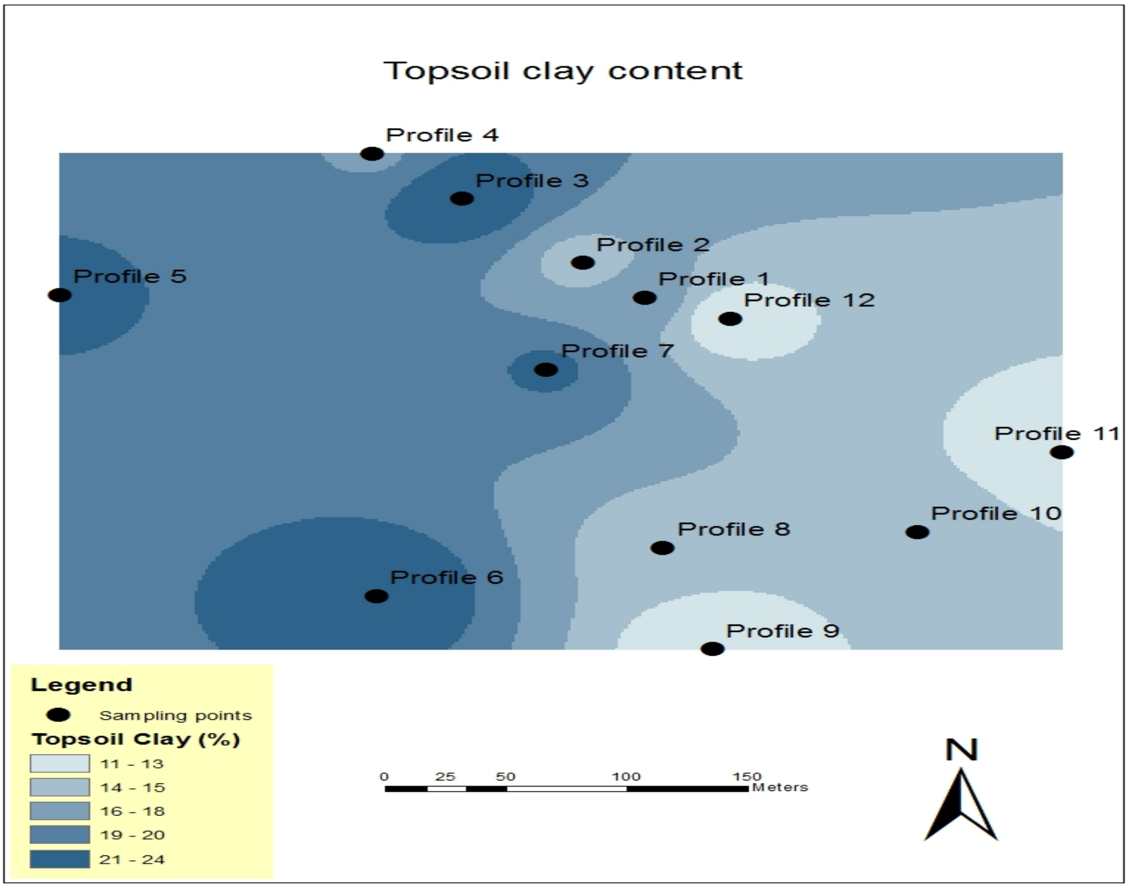

Figure 5: Spatial variability map of topsoil clay content

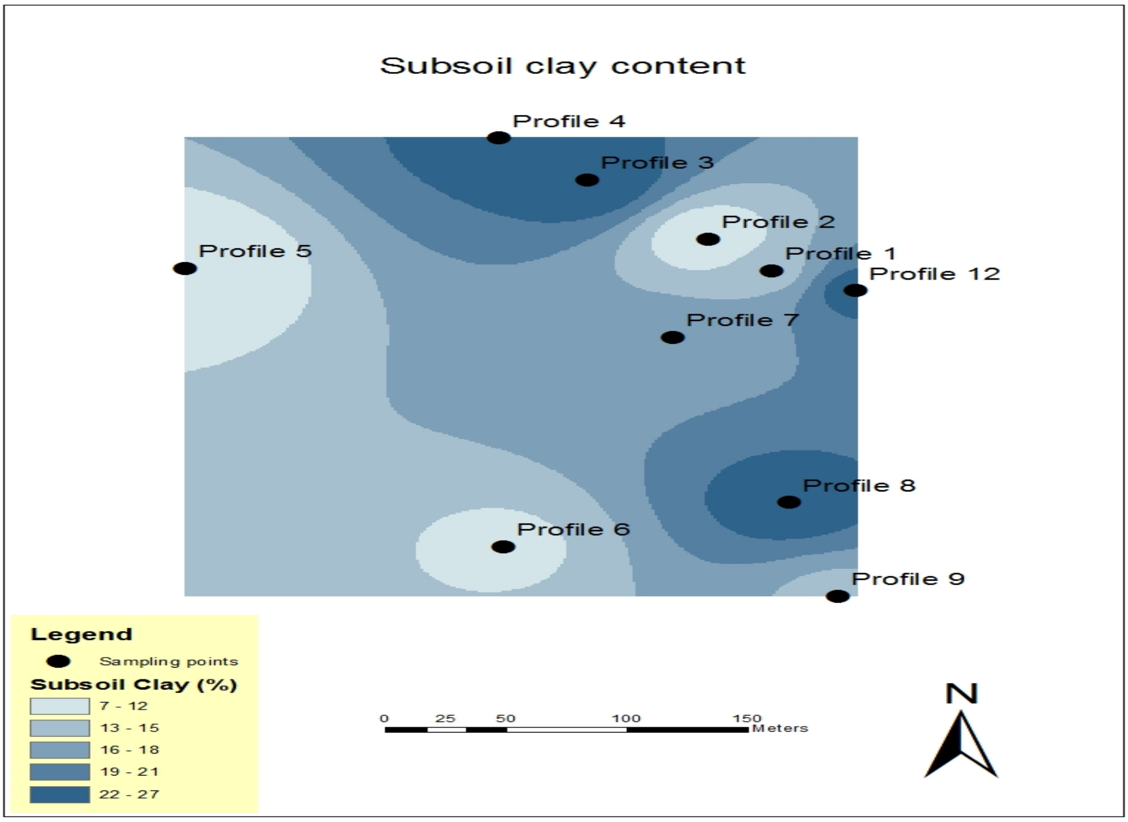

Figure 6: Spatial variability map of subsoil clay content

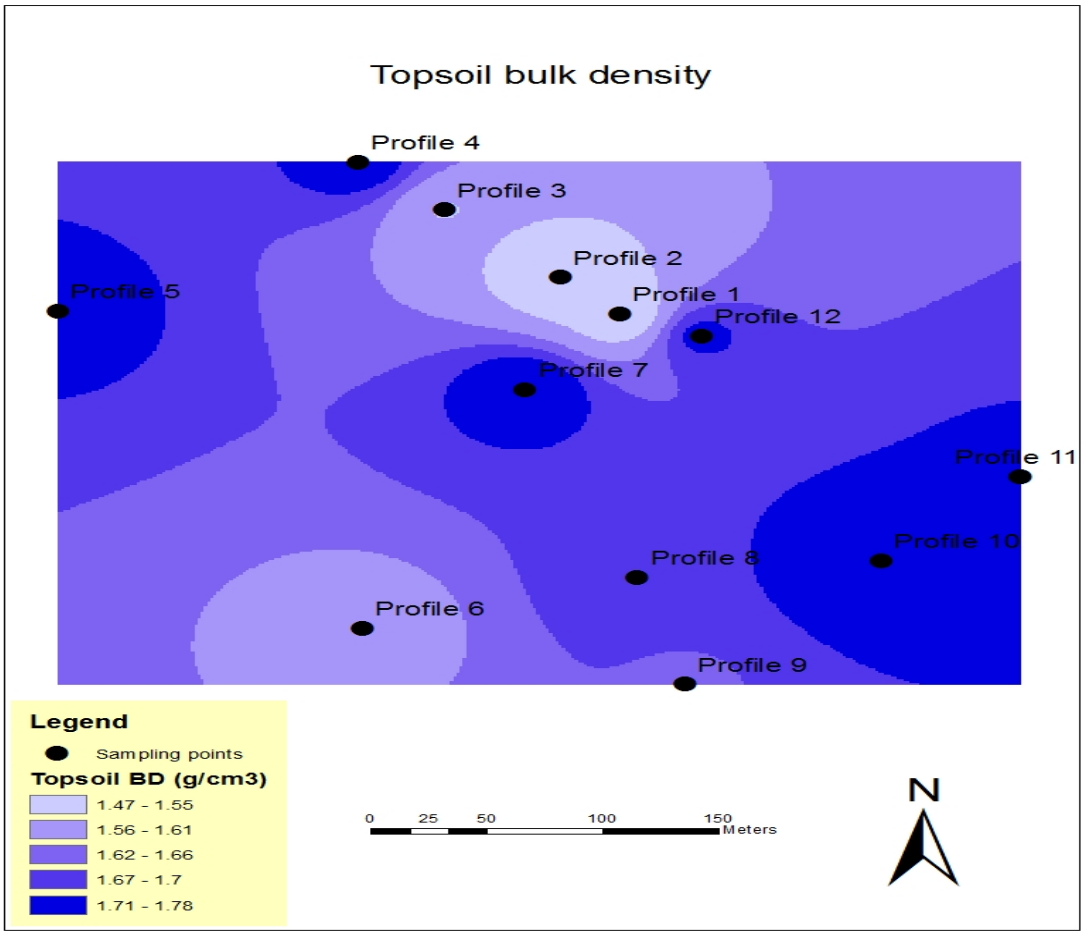

Figure 7: Spatial variability map of topsoil bulk density

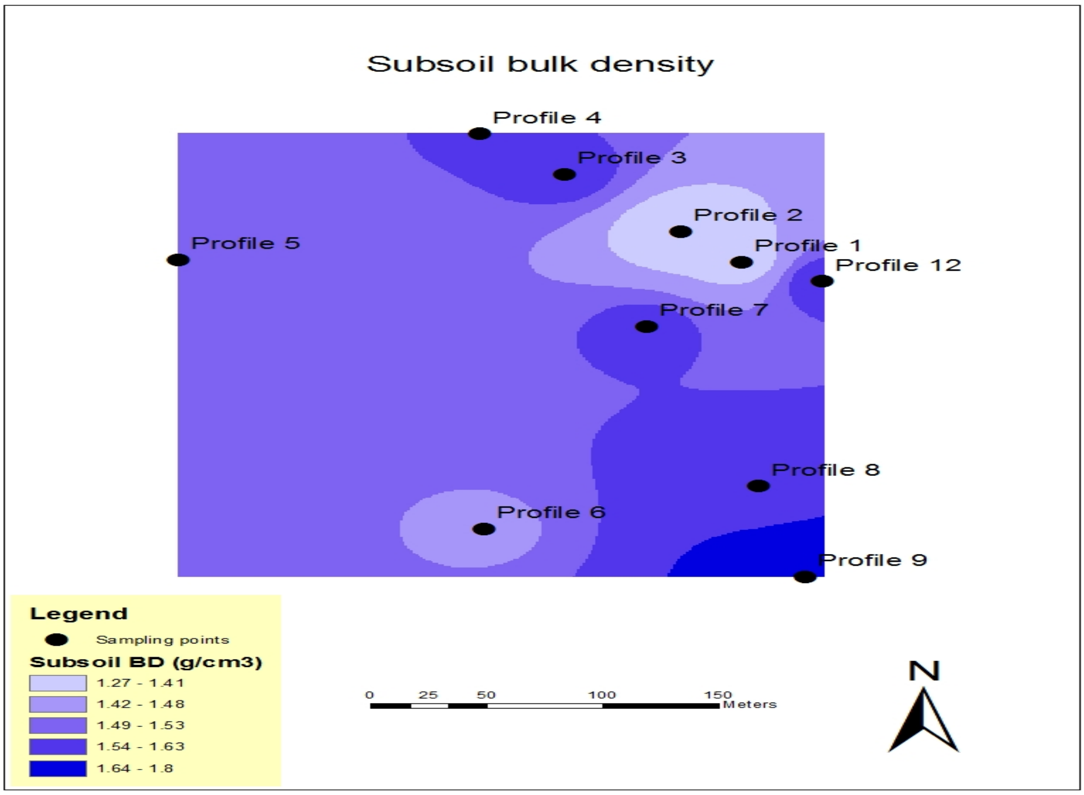

Figure 8: Spatial variability map of subsoil bulk density

Soils with high pH in the topsoil were found in the north, east and south eastern parts of the field while low pH was found in the south and south western parts (Figure 9). Subsoil horizons indicated to be dominated by high pH levels except in the north western and southern parts (Figure 10). The spatial variability maps showed that the distribution of the pH in the topsoil increased from the west to the east and varied as compared to the pH in the subsoil which was more uniform.

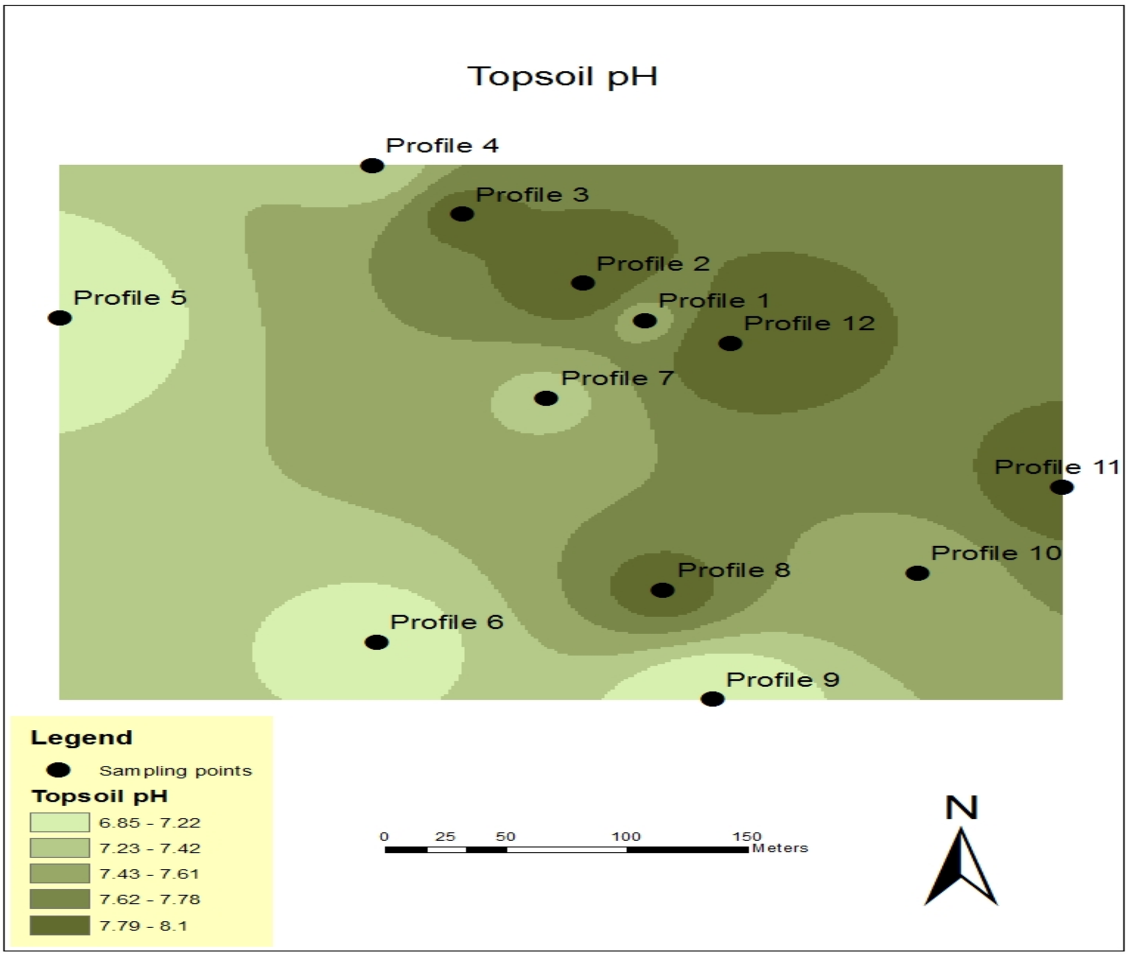

Figure 9: Spatial variability map of topsoil pH

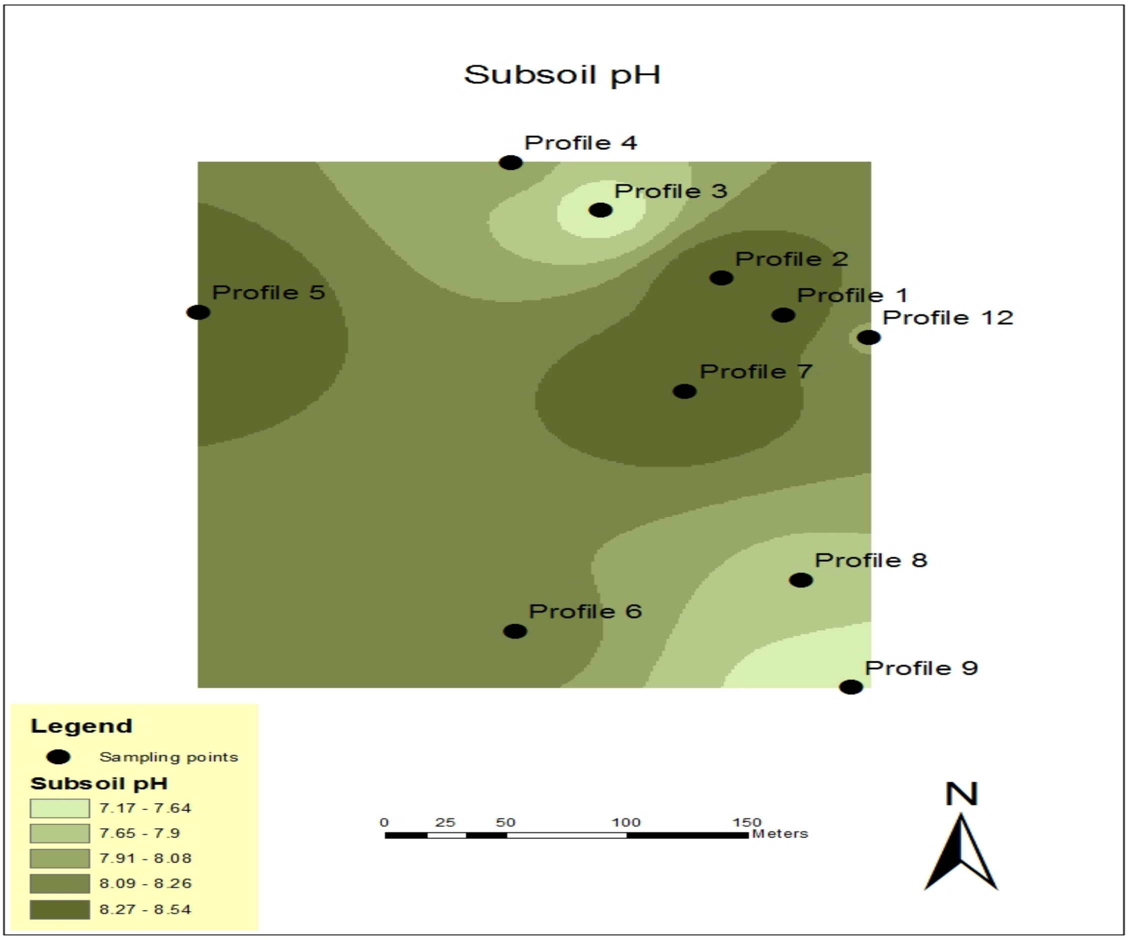

Figure 10: Spatial variability map of subsoil pH

High electrical conductivity in the topsoil horizons was located in the north western part of the field whereas the low electrical conductivity soils were in the south eastern part of the field (Figure 11). Soils with high electrical conductivity in the subsoil horizons were found in the central to western part of the field while soils with low electrical conductivity were in the southern and eastern parts (Figure 12). The maps showed that most parts of the field are generally dominated with low electrical conductivity in the topsoil and a high EC in the subsoil.

Soils with high organic carbon in the topsoil horizons were found in the northern and south western parts of the field whereas those with low organic carbon were in the northern and south eastern parts of the field (Figure 13). Subsoil horizons with high organic carbon were located in the northern and western parts of the field, while soils with low organic carbon are in the north western part of the field (Figure 14). The organic carbon is fairly distributed across the field even though it is very low.

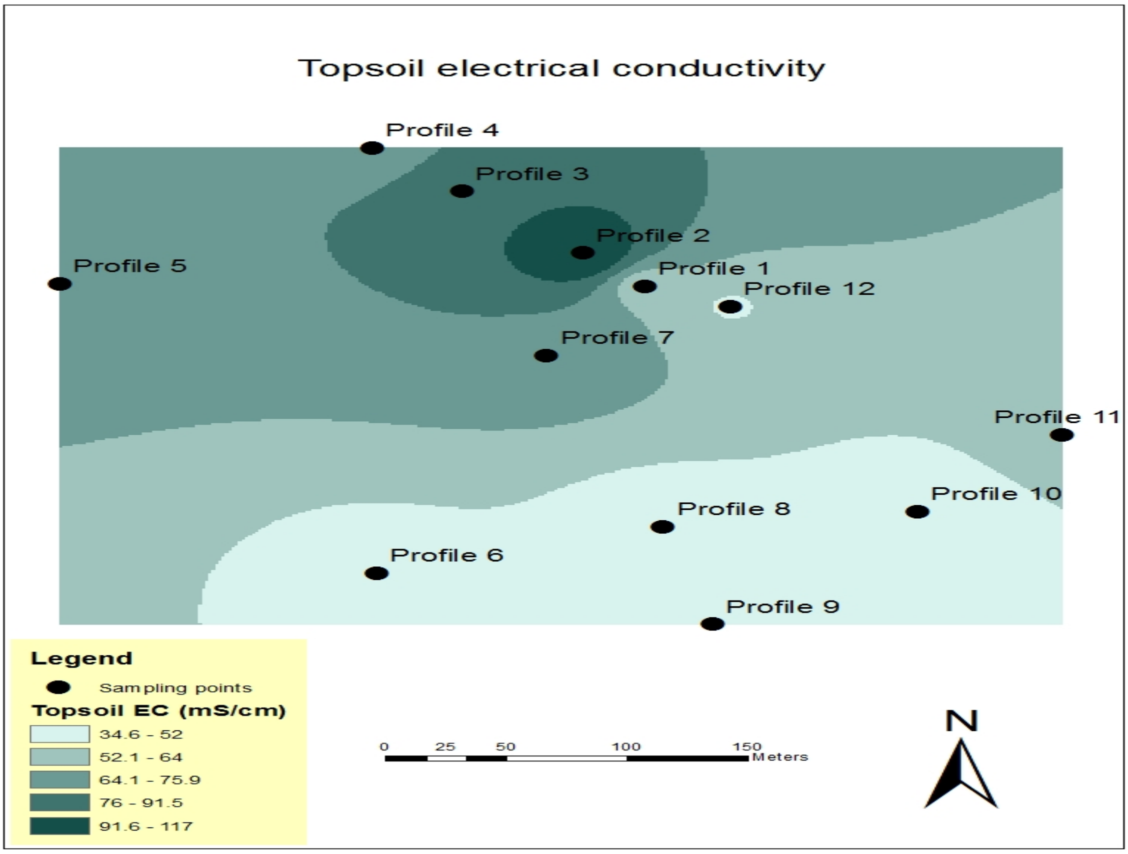

Figure 11: Spatial variability map of topsoil electrical conductivity

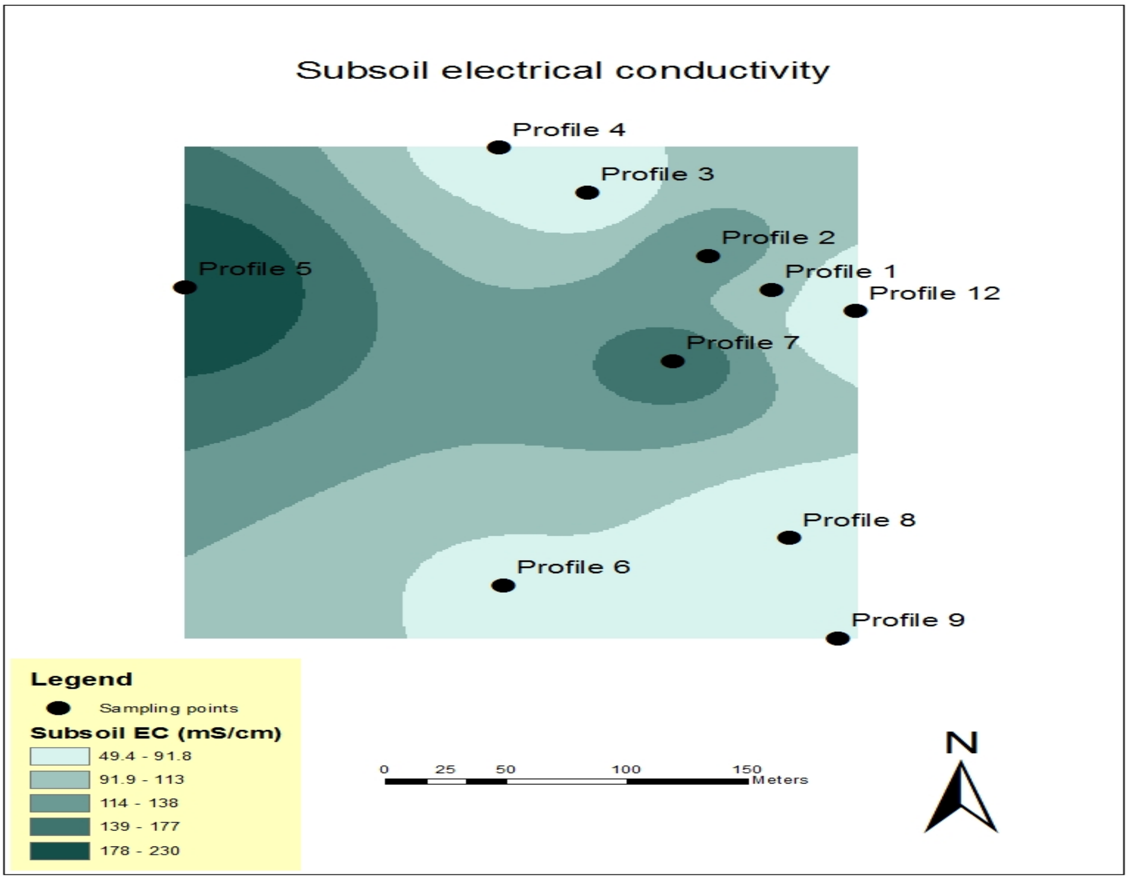

Figure 12: Spatial variability map of subsoil electrical conductivity

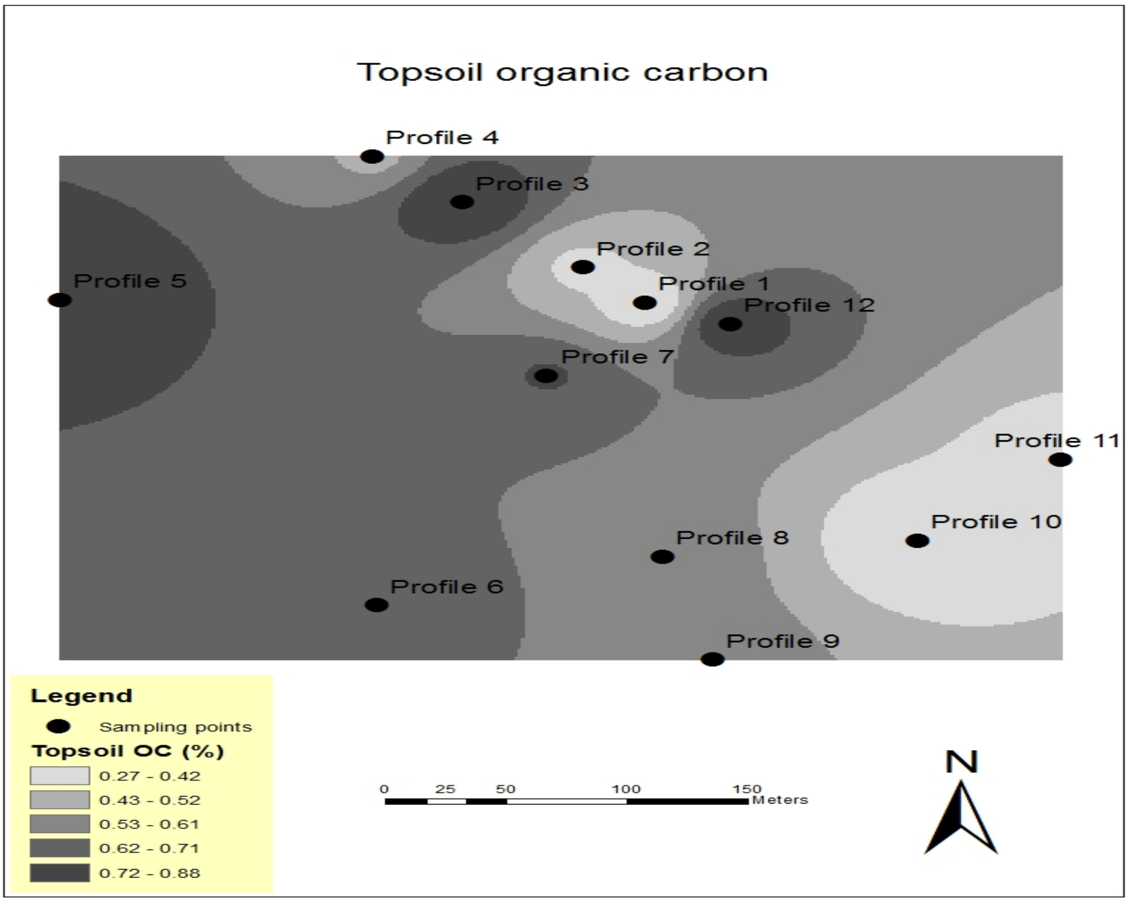

Figure 13: Spatial variability map of topsoil organic carbon

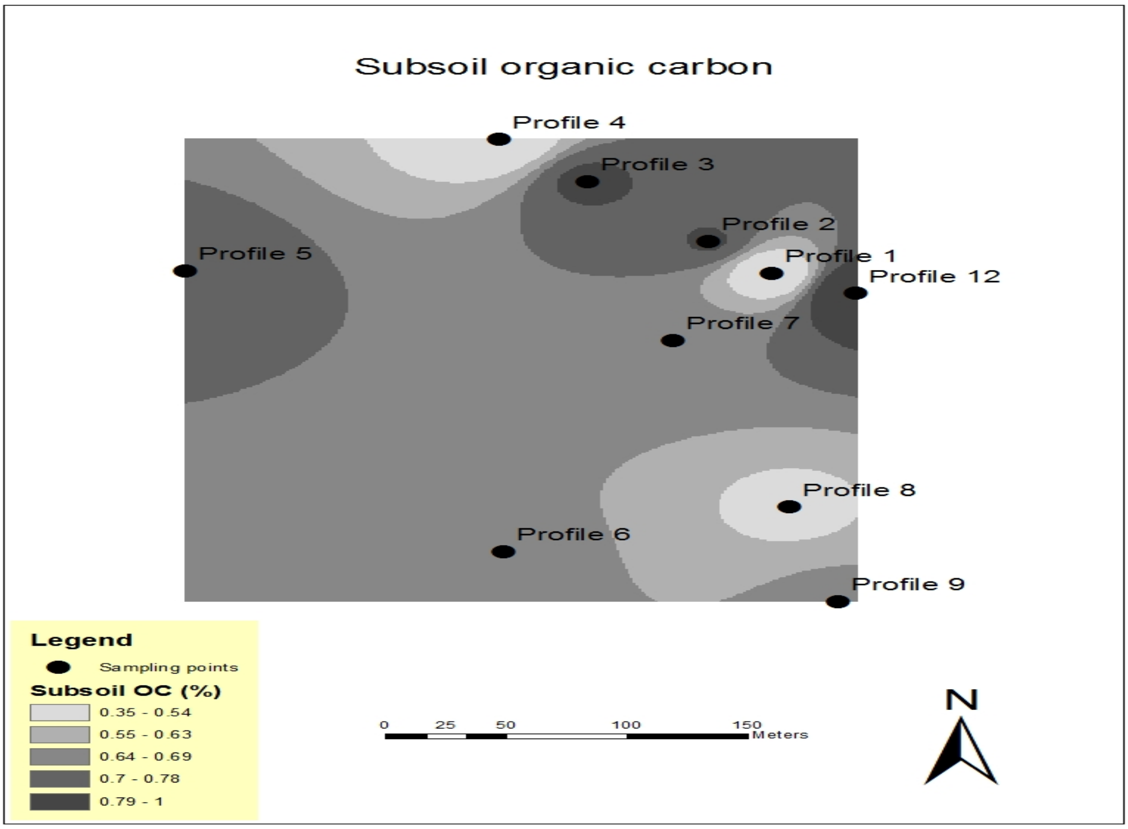

Figure 14: Spatial variability map of subsoil organic carbon

4.4 Spatial distribution of selected measured soil physical and chemical parameters

All the variables in the topsoil and subsoil (Table 8) had low range values (0 – 0.01). The low range values indicated that the spatial dependence occur over short distances which means the spatial variability is high. The variables with nugget/sill ratio values lower than or equal to 25% are considered to have strong spatial dependence, between 25 and 75% are considered to have moderate spatial dependence and more than 75% are considered to have weak spatial dependence (Cambardella *et al*., 1994).

Generally, strong, weak and moderate spatial dependence of soil properties can be attributed to intrinsic factors, extrinsic factors and both intrinsic and extrinsic factors respectively (Behera *et al*., 2011). Spatial dependency of all the variables is shown in terms of nugget/sill ration (Table 8). The spatial dependence of total depth, subsoil pH, EC and sand were weak, this might have been caused by factors such as fertilisation, irrigation water and erosion. Topsoil clay content and pH showed moderate spatial dependence which may be the result of soil forming processes, parent material, erosion and fertilisation. Strong spatial dependence was observed on topsoil EC, OC, sand content and subsoil BD, this may be attributed to parent material and soil forming processes.

Semivariogram graphs (Figure 15 to 27) indicated considerable variability of the soil variables across the research block. Semivariograms show the degree of dissimilarity between observations as a function of distance, observations at each point are likely to be similar to each other. Normally, semivariance increases as the distance between the points grows until at some point the locations are considered independent of each other and semivariance no longer increases (Karl and Maurer, 2010).

The low mean values showed that predicted values were close to the observed values. Negative means indicate that predicted values are less than observed values while positive mean values indicate that predicted values are higher than observed values. The root square mean and average standard error of EC are high because the EC values are higher with a wide range. Generally the prediction errors were low.

Table 8: Semivariogram parameters of the measured soil variables

Soil properties	Nugget	Range	Sill	Nugget/Sill ratio
Total depth	0	0.002	761.524	0
Topsoil				
pH	0.14	0.01	0.21	0.68
EC	449.63	0.00	239.30	1.88
OC	0.05	0.01	0.02	2.71
Clay	16.31	0.01	32.05	0.51
Sand	38.81	0.01	30.97	1.25
BD	0.01	0.01	0	
Subsoil				
pH	0	0.00	0.27	
EC	491.32	0.01	6938.28	0.07
OC	0.05	0.01	0	
Clay	57.33	0.01	0	
Sand	0	0.00	70.86	0
BD	0.02	0.01	0.02	1.06

EC=electrical conductivity, OC=organic carbon, BD=bulk density

Table 9: Prediction errors of the measured soil variables

Soil properties	Mean	Root-Mean-Square	Mean Standardised	Root-Mean-Square Standardised	Average Standard error
Total depth	1.419	20.519	0.054	0.894	23.039
Topsoil					
pH	0.02	0.41	0.02	0.94	0.430
EC	-0.06	20.18	-0.01	0.87	23.79
OC	-0.01	0.22	-0.03	0.97	0.23
Clay	-0.02	4.42	-0.00	0.96	4.64
Sand	-0.12	6.38	-0.01	0.92	7.07
BD	-0.00	0.12	-0.03	1.03	0.12
Subsoil					
pH	0.03	0.45	0.06	1.00	0.45
EC	-4.35	55.61	-0.03	1.03	48.62
OC	0.00	0.24	0.01	1.04	0.23
Clay	-0.59	7.58	-0.08	0.94	8.03
Sand	0.09	8.05	0.02	0.95	8.46
BD	-0.01	0.15	-0.04	1.02	0.15

EC=electrical conductivity, OC=organic carbon, BD=bulk density

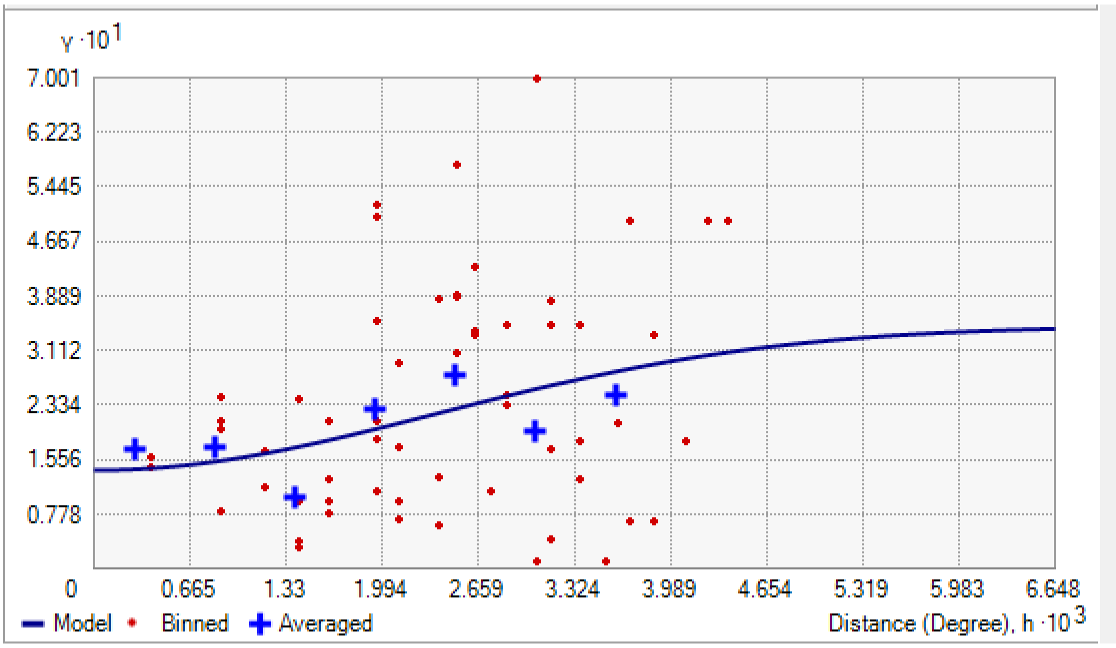

Figure 15: Semivariogram for topsoil pH

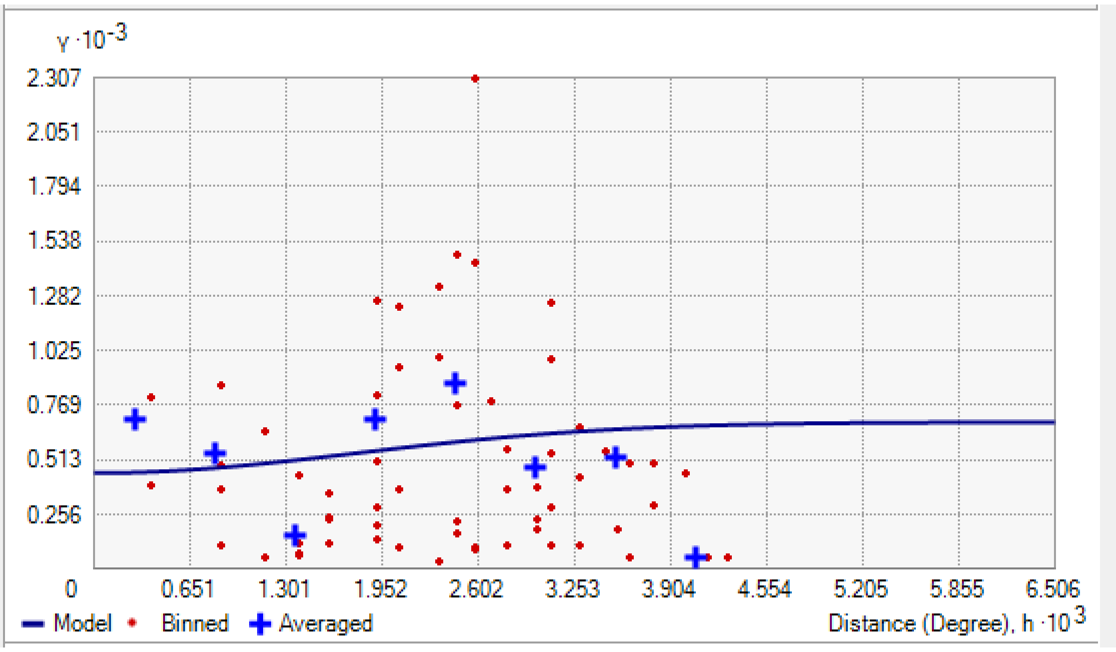

Figure 16: Semivariogram for topsoil electrical conductivity

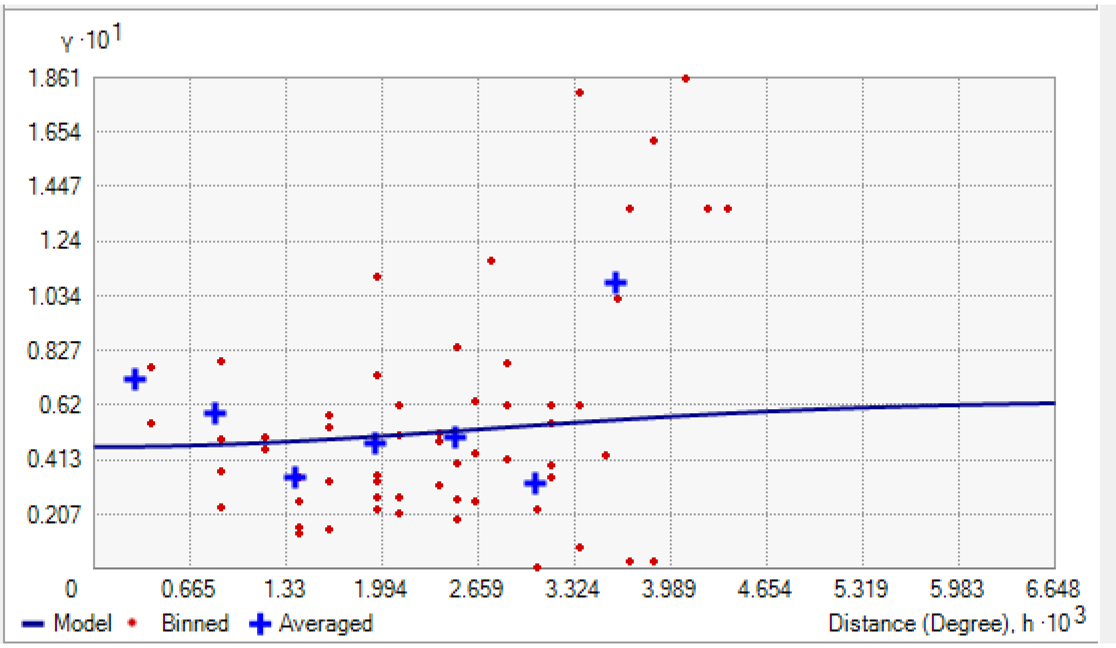

Figure 17: Semivariogram for topsoil organic carbon

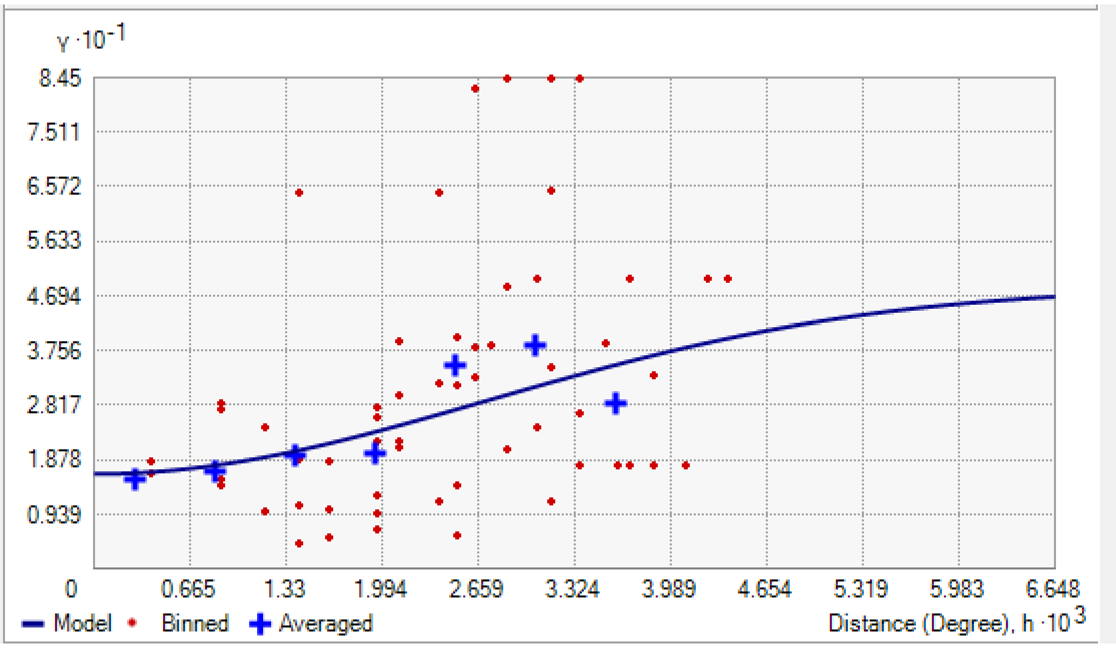

Figure 18: Semivariogram for topsoil clay

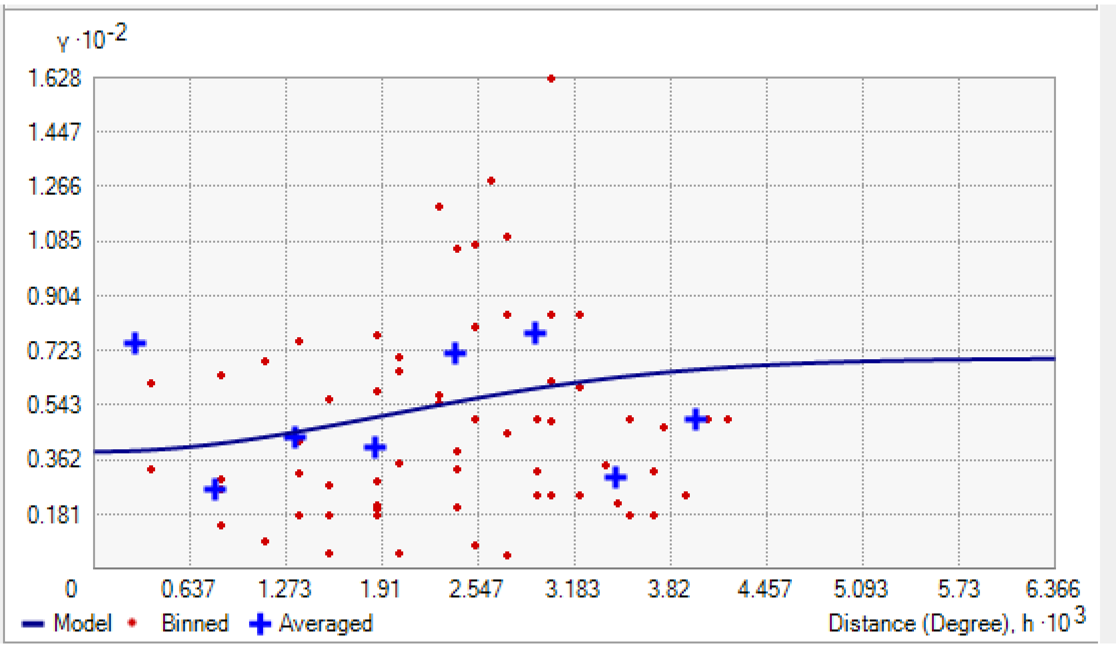

Figure 19: Semivariogram for topsoil sand

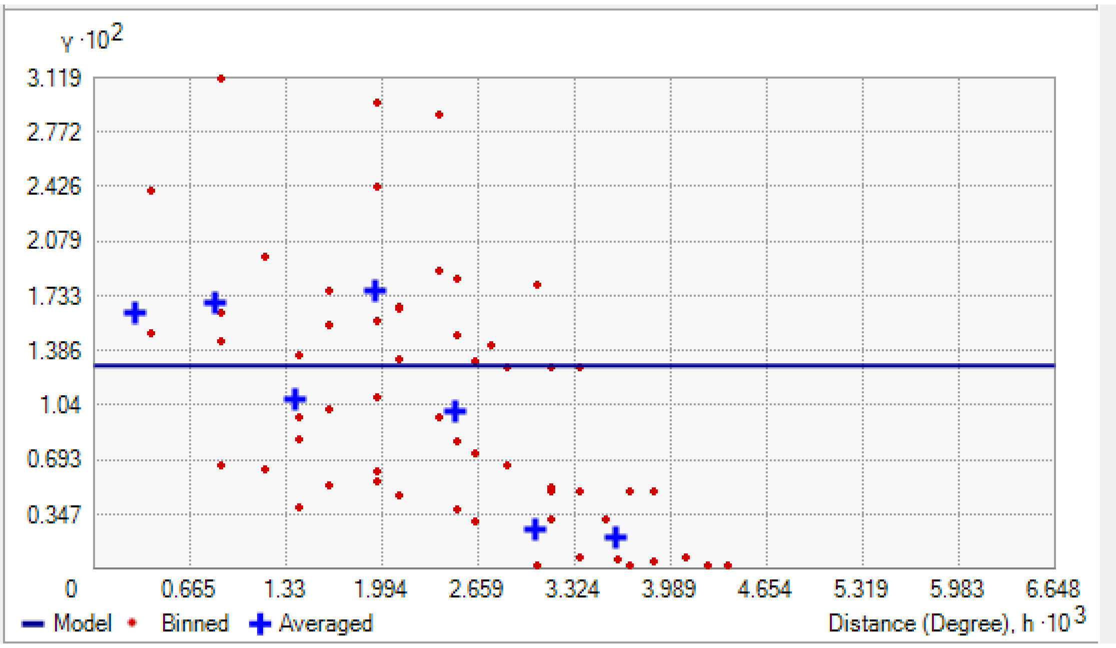

Figure 20: Semivariogram for topsoil bulk density

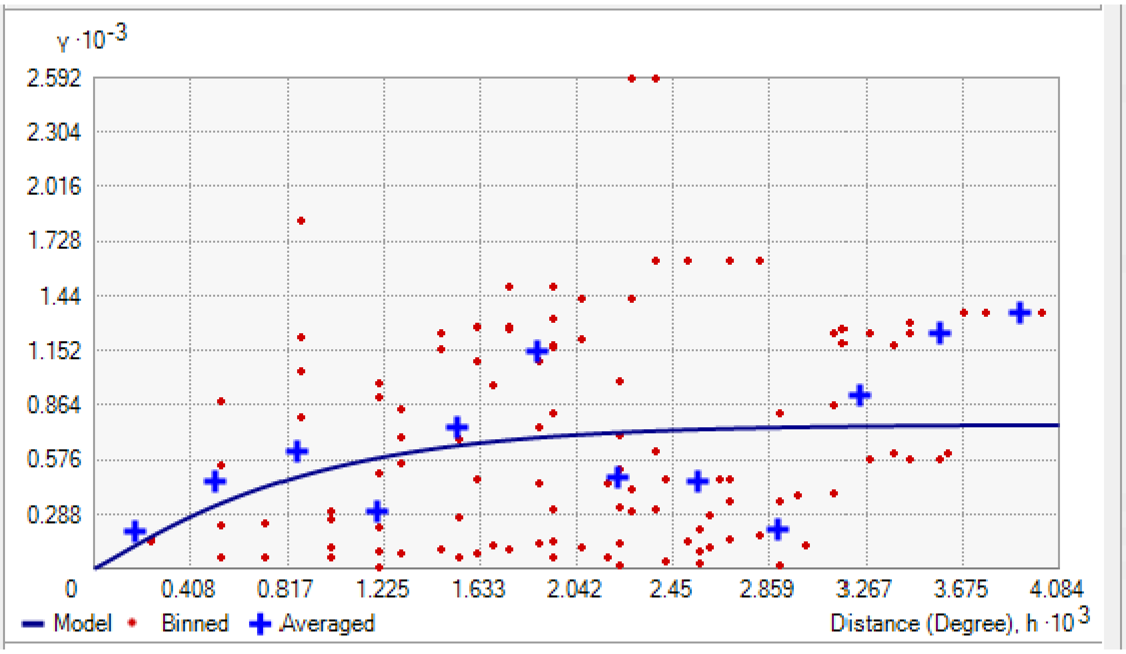

Figure 21: Semivariogram for total soil depth

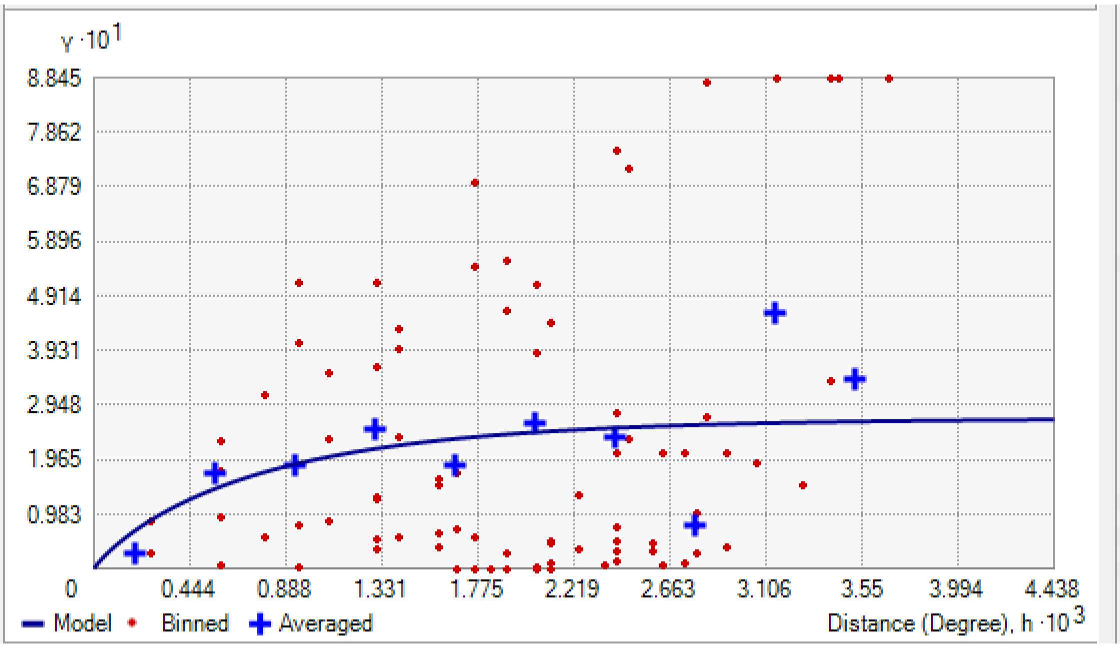

Figure 22: Semivariogram for subsoil pH

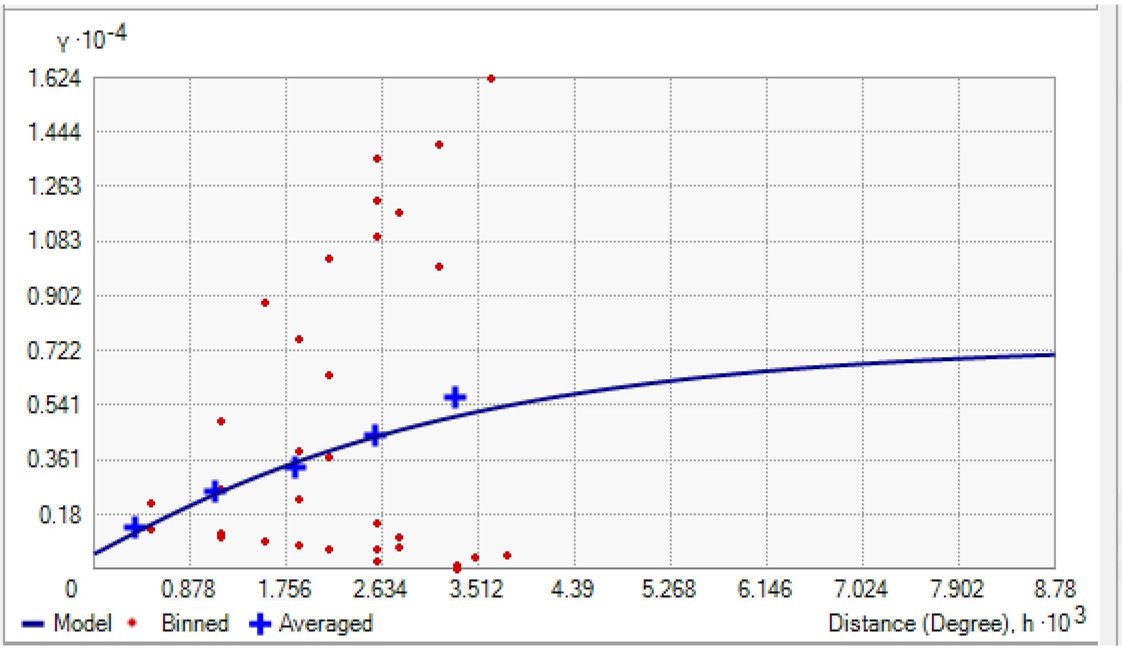

Figure 23: Semivariogram for subsoil electrical conductivity

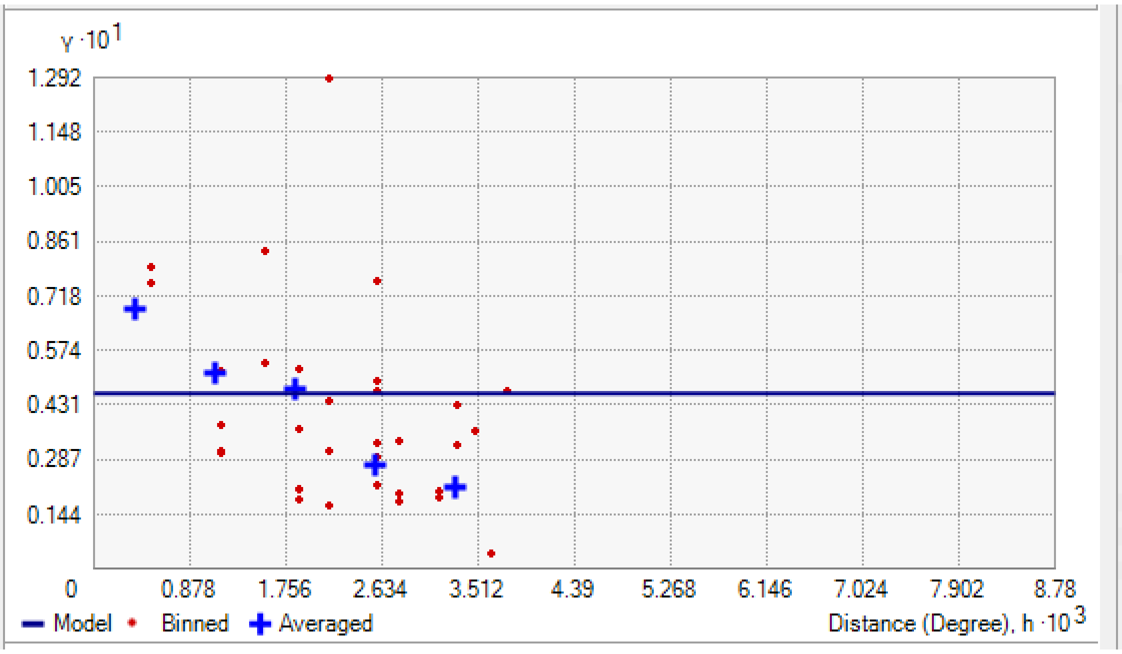

Figure 24: Semivariogram for subsoil organic carbon

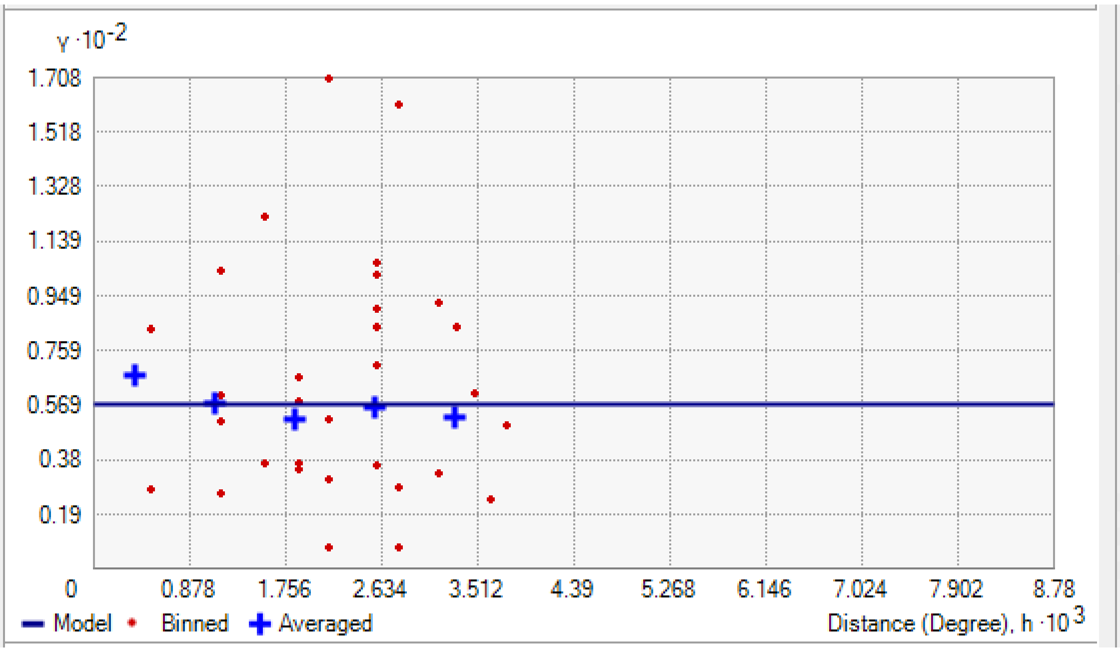

Figure 25: Semivariogram for subsoil clay

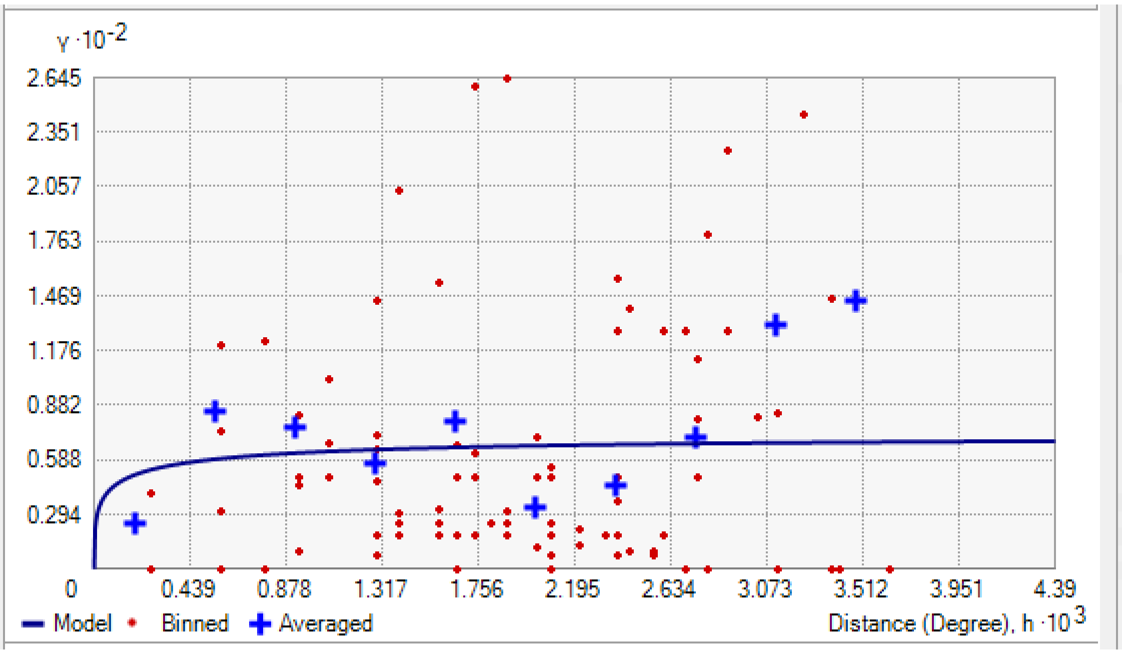

Figure 26: Semivariogram for subsoil sand

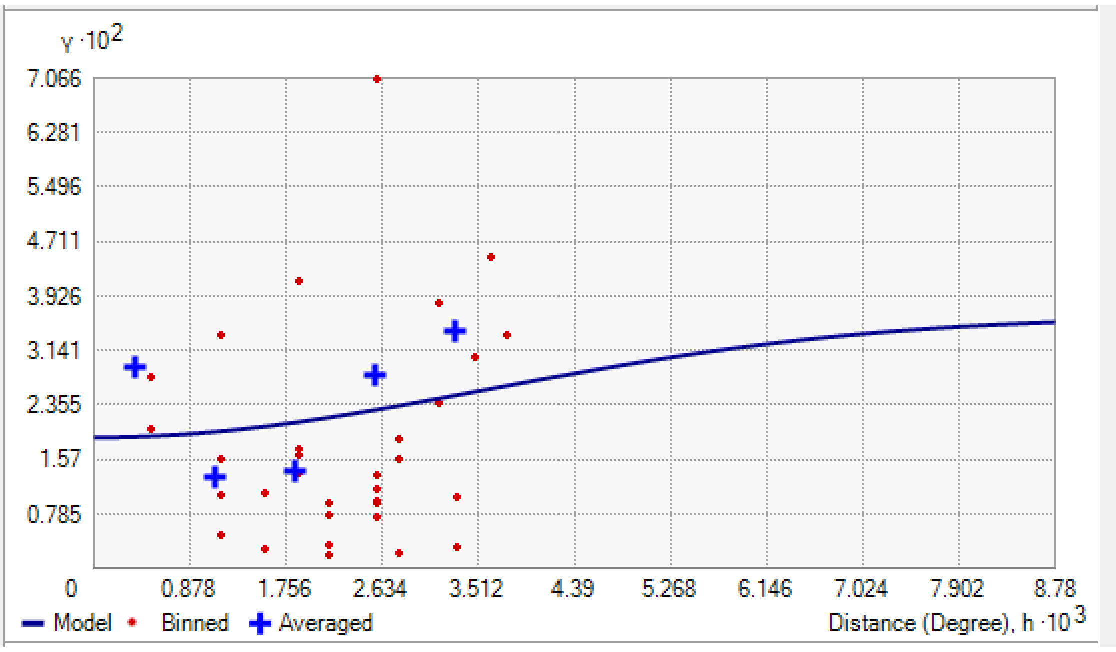

Figure 27: Semivariogram for subsoil bulk density

4.5 Correlations between measured soil parameters

The correlation of the measured parameters shown in Table 10 below indicated that electrical conductivity and effective cations exchange capacity correlated negatively with bulk density, sand and clay content. According to Nath (2014), statistical correlation studies showed significant negative correlations of bulk density with soil pH (r = -0.73) and electrical conductivity (r = -0.70). Positive significant correlation of electrical conductivity was found with extractable calcium, magnesium and sodium, while there was non-significant negative correlation with potassium. Electrical conductivity showed significant negative relationship with available phosphorus (Bray-1 P). Patel *et al*. (2014) discovered correlation studies of pH with electrical conductivity showed strong relationship (r= 0.170) and less negative correlation of electrical conductivity was found with phosphorus (r= -0.082), while positive but not significant correlation was found with organic carbon (r= 0.062). Electrical conductivity also showed a positive non-significant correlation with extractable iron and copper, and non significant negative correlation with zinc and manganese.

Positive significant correlation of electrical conductivity was found with effective cation exchange capacity, pH_W and pH_{KCl} while organic carbon showed a non-significant correlation. Guan *et al*. (2013) found that the amount of organic carbon was significantly and positively correlated with clay content and cation exchange capacity and negatively with pH at the significance level of 0.01. A significant negative correlation was observed between bulk density and electrical conductivity while a non-significant negative correlation was found between electrical conductivity and clay content. Generally pH values were weakly and not significantly correlated with cation exchange capacity and clay content (Guan *et al.,* 2013).

Exchangeable calcium, magnesium and sodium showed to a highly significant positive correlation with effective cation exchange capacity while potassium showed no significant positive correlation with effective cation exchange capacity. Available phosphorus (Bray-1 P) was found to have significant negative correlation with effective cation exchange capacity. A positive significant correlation of effective cation exchange capacity was found with extractable iron and copper while there was no significant positive correlation and significant negative correlation with extractable manganese and zinc respectively. Both pH_W and pH_{KCl} showed a significant positive correlation with effective cation exchange capacity while non-significant positive correlation was found between organic carbon and effective cation exchange capacity. Non significant negative correlation was observed between clay content and ECEC. A positive non significant correlation of bulk density was found with clay, sand and organic carbon. Among all the measured parameters only exchangeable calcium, magnesium and sodium showed high degree positive and highly significant correlation with electrical conductivity and ECEC. However, electrical conductivity also showed high degree positive and significant correlation with ECEC, magnesium and calcium while ECEC showed the same high degree of a significant positive correlation with calcium, magnesium and sodium.

Table 10: Pearson correlation matrix between soil properties

Parameters	EC	ECEC	OC	BD	Clay	Sand	Mg	Ca	Na	K	P	Mn	Cu	Zn	Fe	pH_{KCl}	pH_W
EC																	
ECEC	0.891***																
OC	0.142	0.187															
BD	-0.519	-0.689**	0.040														
Clay	-0.334	-0.150	0.201	0.169													
Sand	-0.057	-0.282	-0.040	0.330	-0.804***												
Mg	0.871***	0.967***	0.137	-0.698**	-0.106	-0.337											
Ca	0.849***	0.953***	0.234	-0.593*	-0.217	-0.161	0.849***										
Na	0.707**	0.775***	-0.012	-0.779***	-0.059	-0.391	0.878***	0.585*									
K	-0.109	0.002	0.109	0.036	0.252	-0.161	-0.095	0.042	-0.270								
P	-0.519	-0.630*	-0.088	0.580*	-0.151	0.508	-0.001**	-0.526	-0.749***	0.429							
Mn	-0.022	0.027	-0.033	0.038	0.037	-0.116	-0.049	0.080	-0.192	0.502	0.408						
Cu	0.256	0.443	0.366	-0.509	0.329	-0.551	0.4300	0.390	0.371	0.256	-0.579*	-0.018					
Zn	-0.327	-0.478	-0.802	0.538*	-0.206	0.470	-0.547*	-0.367	-0.622*	0.330	0.864***	0.636*	-0.574*				
Fe	0.256	0.459	0.016	-0.214	0.217	-0.316	0.468	0.375	0.320	0.423	-0.175	0.109	0.381	-0.160			
pH_{KCl}	0.698**	0.628*	-0.078	-0.451	-0.534	0.151	0.651**	0.564*	0.557*	-0.191	-0.302	-0.047	0.113	-0.276	0.195		
pH_W	0.664**	0.604*	0.001	-0.614*	-0.355	-0.023	0.681**	0.473	0.744***	-0.325	-0.414	-0.156	0.129	-0.400	0.149	0.808***	

EC= electrical conductivity; ECEC=effective cation exchange capacity; OC= organic carbon; BD=bulk density; * implies significant at $P<0.05$; ** implies significant at $P<0.01$; *** implies significant at $P<0.001$

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The results of this study revealed that there is variability among the soil physical and chemical parameters within the research block which may be a result of land uses and management or natural factors such as climate and topography. Generally the chemical properties were more variable than the physical properties. The distribution of some variables was normal while others were not normally distributed, possibly due to the influence of previous and current soil management and land uses. There exists a fairly high level of spatial variability of soil physico-chemical properties horizontally and vertically across the research block; and the soils are generally shallow. In general the spatial variability of the characterized parameters was significant across the research block. Of all the measured parameters, electrical conductivity, Bray-1 P, exchangeable K, Ca and Na as well as extractable Fe and Zn showed a huge percent variation across the different depth and locations across the field. The correlation analyses indicated that there is negative and positive inverse or direct relationship among the measured soil physical and chemical properties. A strong positive relationship was observed between exchangeable cations namely magnesium, calcium and sodium, electrical conductivity and effective cation exchange capacity. This study provided quantitative information for monitoring changes in soil properties and improving soil management practices thereby enhancing the fertility and productivity of the soils in the research block. In addition, the variability of the measured soil chemical and physical parameters will help to explain eventual anomalies of the results of future planned experiments.

It is recommended that adequate fertilization and good crop and/or soil management are practiced based on the soil variability in the research block. This will help to improve the productivity and fertility of the soils within the research block for sustainable production. Soil pH should be adjusted to the recommend level to achieve utmost balanced nutrients availability. Soils with high clay content should be irrigated less frequently than those with high sand content, but with greater quantity of water and over longer periods. It is also advisable to return crop residues to soil as this will improve soil physical and chemical conditions. Regular soil analyses should be conducted at least every planting season to address physico-chemical changes in time depending on the research schedule to avoid failure or delay of the experiments. Thus, there is a need to find the degree to which soil properties vary under different land uses, so as to provide better understanding for effective soil management and contribute significantly to the good choice of appropriate land use. Inputs should be varied accordingly to meet the needs of the varying soil conditions across the research block.

LIST OF REFERENCES

AFZALINIA, S., SOLHJOU, A.A. and ESKANDARI, I. 2011. Effects of subsoiling on some soil physical properties and wheat yield in a dry land ecological condition. *Journal of Agricultural Science and Technology* 1: 842-847.

AGOUME, V. and BIRANG, A.M. 2009. Impact of land-use systems on some physical and chemical soil properties of an oxisol in the humid forest zone of Southern Cameroon. *Tropicultura* 27: 15-20.

ARAIN, M.A., AHMED, M. and KHAN, M.A. 2000. Some physic-chemical characteristics of soil in sugarcane cultivated areas of Nawabshah, Sindh, Pakistan. *Pakistan Journal of Botany* 32: 93-100.

ATKINSON, B.S., SPARKES, D.L. and MOONEY, S.J. 2009. The impact of soil structure on the establishment of winter wheat (*Triticum aestivum*). *European Journal of Agronomy* 30: 243-257.

BABU, M.V.S., REDDY, C.M., SUBRAMANIAM, A. and BALAGURAVAIAH, D. 2007. Effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane. *Journal of the Indian Society of Soil Science* 55: 161-166.

BAI, Y. and WANG, Y. 2011. The spatial variability of soil chemical properties in a jujube slope on the loess plateau of China. *Soil Science* 176: 550-558.

BARUAH, B.K., DAS, B., HAQUE, A., MEDHI, C. and MISRA, A.K. 2011. Sequential extraction of common metals (Na, K, Ca and Mg) from surface soil. *Journal of Chemical and Pharmaceutical Research* 3: 565-573.

BEHERA, S.K., SINGH, M.V., SINGH, K.N. and TODWAL, S. 2011. Distribution variability of total and extractable zinc in cultivated acid soils of India and their relationship with some selected soil properties. *Geoderma* 162: 242-250.

BELL, R.W. and DELL, B. 2008. Micronutrients for Sustainable Food, Feed, Fibre and Bioenergy Production. First edition, IFA, Paris, France (www.fertilizer.org).

BOLVIN, P., SCHAFFERR, B. and STURNY, N. 2009. Quantifying relationship between soil organic carbon and soil physical properties using shrinkage modelling. *European Journal of Soil Science* 60: 265-275.

BOUMA, J., STOORVOGEL, J., VAN ALPHEN, B.J. and BOOLTINK, H.W.G. 1999. Pedology, precision agriculture, and the changing paradigm of agricultural research. *Soil Science Society of America Journal* 63: 1763-1768.

BOUYOUCOS, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* 54: 464-465.

BRADY, N.C. and WEIL, R.R. 2005. The Nature and Properties of Soil. Macmillan Publishing Co., New York, USA.

BRONICK, C.K. and LAL, R. 2004. Soil structure and management: A review. *Geoderma* 124: 3-22.

BROUDER, S., HOFMANN, B. and REETZ, Jr., H.F. 2001. Evaluating spatial variability of soil parameters for input management. *Better Crops* 85: 8-11.

BUOL, S.W., SOUTHARD, R.J., GRAHAM, R.C. and McDANIEL, P.A. 2011. Soil genesis and classification. John Wiley and sons, Inc. UK.

BURGOS, P., MADEJÓN, E., PÉREZ-DE-MORA, A. and CABRERA, F. 2006. Spatial variability of the chemical characteristics of a trace-element-contaminated soil before and after remediation. *Geoderma* 130: 157-175.

BURROUGH, P.A. 1993. Soil variability: a late 20th century view. *Soils Fertility* 56: 529-562.

CAMBARDELLA, C.A., MOORMAN, T.B., NOCAK, J.M., PARKIN, T.B., KARLEN, D.L., TURCO, R.F., and KONOPKA, A.E. 1994. Field-scale variability of soil properties in central Iowa soils. *Soil Science Society of America Journal* 58: 1501-1511.

CAMPBELL, D.J. and HENSHALL, J.K. 1991. Bulk Density. In: Soil Analysis-Physical methods; Smith, K.A. and Mullins, C.E., Eds. Mareel Dekker, New York.

CASTRIGNANÒ, A., GIUGLIARINI, L., RISALITI, R. and MARTINELLI, N. 2000. Study of spatial relationships among some soil physico-chemical properties of a field in central Italy using multivariate geostatistics. *Geoderma* 97: 39-60.

CERRI, C.E.P., BERNOUX, M., CHAPLOT, V., VOLKOFF, B., VICTORIA, R.L., MELILLO, J.M., PAUSTIAN, K. and CERRI, C.C. 2004. Assessment of soil property spatial variation in an Amazon pasture: Basis for selecting an agronomic experimental area. *Geoderma* 123: 51-68.

CHAUDHARI, P.R., AHIRE, D.V. and AHIRE, V.D. 2012. Correlation between physico-chemical properties and available nutrients in sandy loam soils of Haridwar. *Journal of Chemical, Biological and Physical Sciences* 2: 1493-1500.

CHAUDHARI, P.R., AHIRE, D.V., AHIRE, V.D., CHKRAVARTY, M. and MAITY, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications* 3: 1-8.

CHHABRA, G., SRIVASTAVA, P.C., GHOSH, D. and AGNIHOTRI, A.K. 1996. Distribution of available micronutrient cations as related to soil properties in different soil zones of Gola-Kosiinterbasin. *Crop Research-Hisar* 11: 296-303.

CHIK, Z. and ISLAM, T. 2011. Study of chemical effects on soil compaction characterizations through electrical conductivity. *International Journal of Electrochemical Science* 6: 6733-6740.

CHU, C. and JOHNSON, L.J. 1985. Relationship between exchangeable and total magnesium in Pennylvania soils. *Clays and Clay Minerals* 33: 340-344.

CORWIN, D.L. and LESCH, S.M. 2003. Application of soil electrical conductivity to precision agriculture: Theory, principles and guidelines. *Agronomy Journal* 95: 455-471.

DANIELS, R.B., GILLIAM, J.W., CASSEL, D.K. and NELSON, L.A. 1987. Quantifying the effects of past soil erosion on present soil productivity. *Journal of Soil and Water Conservation* 42: 183-187.

DEBNATH, P., DEB, P., SEN, D., PATTANNAIK, S.K, SAH, D. and GHOSH, S.K. 2012. Physico-chemical properties and its relationship with water holding capacity of cultivated soils along altitudinal gradient in Sikkim. *International Journal of Agriculture, Environment and Biotechnology* 2: 161-166.

DEPARTMENT OF ENVIRONMENT AND PRIMARY INDUSTRIES, 2003. Soil physical properties: Texture and structure. Available online at http://www.depi.vic.gov.au/agriculture-andfood/farm-management/soil-andwater/soils/soil-physical-properties. Accessed on 08/02/2014

DERPSCH, R. 2007. The no-tillage revolution in South America. In: Proceedings of the Conference on Farm Technology, Edmonton, Alberta, Canada, pp. 54-68.

DRINKWATER, L.E., WAGONER, P. and SARRANTONIO, M. 1998. Legume based cropping systems have reduced carbon and nitrogen losses. *Nature* 396: 262-265.

FAGERIA, V.D. 2001. Nutrient interactions in crop plants. *Journal of Plant Nutrition* 24: 1269-1290.

FU, W.J., TUNNEY, H. and ZHANG, C.S. 2010. Spatial variation of soil nutrients in a dairy farm and its implications for site-specific fertilizer application. *Soil and Tillage Research* 106: 185-193.

GODWIN, R.J. and MILLER, P.C.H. 2003. A review of the technologies for mapping within-field variability. *Biosystems Engineering* 84: 393-407.

GOOVAERTS, P. 1998. Geostatistical tools for characterizing the spatial variability of microbiological and physico-chemical soil properties. *Biology and Fertility of Soils* 27: 315-334.

GUAN, Y., WEI, J., ZHANG, D., ZU M. and ZHANG, L. 2013. To identify the important soil properties affecting dinoseb adsorption with statistical analysis. *The Scientific World Journal* 2013: 1-7.

GULER, M., ARSALAN, H., CEMEK, B. and ERSAHIN, S. 2014. Long term changes in spatial variation of soil electrical conductivity and exchangeable sodium percentage in irrigated Mesic Ustifluvents. *Agricultural Water Management* 135: 1-8.

GUNAPALA, N. and SCOW, K. 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. *Soil Biology and Biochemistry* 30: 805-816.

HABY, V.A., RUSSELLE, M.P. and SKOGLEY, E.O. 1990. Soil Testing for Potassium, Calcium and Magnesium. In: R. L. Westerman (ed.). *Soil Testing and Plant Analysis*, 3rd ed. Soil Sci. Soc. Am. Inc., Madison, Wisconsin, USA, 181-228.

HEIL, K. and SCHMIDHALTER, U. 2011. Characterisation of soil texture variability using the apparent soil electrical conductivity at a highly variable site. *Computers and Geosciences* 39: 98-110.

HERENCIA, J.F., MAQUEDA, C., GARCIA GALAVIS, P.A., MORENO, R. and RUIZ, J.C. 2008. Physical and chemical properties in soils in conversion to organic management. 6th International Meeting on Soil Fertility Land Management and Agroclimatology, Kusadasi-Aydin, Turkey. 29 October-1 November 2008.

HOLLAND, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems and Environment* 103: 1-25.

HORN, R. and SMUCKER, A. 2005. Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. Soil and Tillage Research 82: 5-14.

HULUGALLE, N.R., LOBRY DE BRUYN, L.A. and ENTWISTLE, P. 1997. Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton. *Applied Soil Ecology* 7: 11-30.

INMAN, D.J., KHOSLA, R. and WESTFALL, D.G. 2005. Nitrogen uptake across site-specific management zones in irrigated corn production systems. *Agronomy Journal* 97: 169-176.

IQBAL, J., THOMASSON, J.A., JENKINS, J.N., OWENS, P.R. and WHISLER, F.D. 2005. Spatial variability analysis of soil physical properties of alluvial soils. *Soil Science Society of America Journal* 69: 1338-1350.

JAKOVLJEVIC, M.D., KOSTIC, N.M. and ANTIC-MLADENOVIC, S.B. 2003. The availability of base elements (Ca, Mg, K and Na) in some important soil types in Serbia. *Proceedings for Natural Sciences, Matica Srpska Novi Sad* 104: 11-2.

JAT, N.L., JATIN, N.K. and CHOUDARY, G.R. 2006. Integrated nutrient management in fenugreek (*Trigonellafoenum-graecum*). *Indian Journal of Agronomy* 51: 331-333.

JUNIOR, V.V., CARVALHO, M.P., DAFONTE, J., FREDDI, O.S., VA'ZQUEZ, E.V. and INGARAMO, O.E. 2006. Spatial variability of soil water content and mechanical resistance of Brazilian ferralsol. *Soil and Tillage Research* 88: 166-177.

KARL, J.W. and MAURER, B.A. 2010. Spatial dependency of predictions from image segmentation: a variogram-based method to determine appropriate scales for producing land-management information. *Ecological Informatics* 5: 194-202.

KIBBLEWHITE, M.G., RITZ, K. and SWIFT, M.J. 2008. Soil health in agricultural systems. *The Royal Society* 363: 685-701.

KILIC, K., OZGOZ, E. and AKBAS, F. 2004. Assessment of spatial variability in penetration resistance as related to some soil physical properties of two fluvents in Turkey. *Soil Tillage Research* 76: 1-11.

KILIC, K., KILIC, S. and KOCYIGIT, R. 2012. Assessment of spatial variability of soil properties in areas under different land uses. *Bulgarian Journal of Agricultural Science* 18: 722-732.

KINYANGI, J. 2007. Soil Health and Soil Quality: A Review. Available online at http://www.cornell.edu.org. Accessed on 27/11/2014.

LAL, R. 2006. Encyclopedia of soil science. Taylor and Francis, Florida.

LIEBHARDT, W.C., ANDREWS, R.W., CULIK, M.N., HARWOOD, R.R., JANKE, R.R., RADKE, J.K. and RIEGER-SCHWARTZ, S.L. 1989. Crop production during conversion from conventional to low-input methods. *Agronomy Journal* 81: 150-159.

LOGSDON, S.D. and KARLEN, D.L. 2004. Bulk density as a soil quality indicator during conversion to no-tillage. *Soil and Tillage Research* 78: 143-149.

LYNCH, J.P. and DEIKMAN, J. 1998. Phosphorus in plant biology: regulatory roles in molecular, cellular, organismic, and ecosystem processes. *In* Lynch, J. P. and Deikman, J. (eds.) Current Topics in Plant Physiology: An American Society of Plant Physiologists Series. American Society of Plant Physiologists, Rockville.p 19.

MACE, J.E. and AMRHEIM, C. 2001. Leaching and reclamation of a soil irrigated with moderate SAR waters. *Soil Science Society of America Journal* 65: 199-204.

MALECKA, I., BLECHARCZYK, A., SAWINSKA, Z. and DOBRZENIECKI, T. 2011. The effect of various long-term tillage systems on soil properties and spring barley yield. *Turkish Journal of Agriculture and Forestry* 36: 217-226.

MARIBENG, L. 2007. The influence of parent material (granite and schist) on physical and chemical properties of soils on the Syferkuil Experimental Farm. University of Limpopo (Turfloop Campus). Available online at http://hdl.handle.net /10386/606. Accessed on 03/11/2012

MAYLAND, H.F. and WILKINSON, S.R. 1989. Soil factors affecting magnesium availability in plant-animal systems: A review. *Journal of Animal Science* 67: 3437-3444.

MILNE, E. 2012. Soil organic carbon. Available online at http://www.eoearth.org /view/article/156087. Accessed on 13/02/2014

MISSISSIPPI AGRICULTURAL AND FORESTRY EXPERIMENT STATION. 2010. Available online at http://msucares.com/crops/soils/phosphorus.html. Accessed on 05/03/2014

MOLIN, J.P. and FAULIN, G.C. 2012. Spatial and temporal variability of soil electrical conductivity related to soil moisture. *Scientia Agricola* 70: 1-5.

MORALES, L.A., VÁZQUEZ, E.V. and PAZ-FERREIRO, J. 2014. Spatial Distribution and Temporal Variability of Ammonium-Nitrogen, Phosphorus, and Potassium in a Rice Field in Corrientes, Argentina. *The Scientific World Journal* 2014: 1-12.

MOSHIA, M.E., MASHATOLA, M.B., SHAKER, P., FOUCHE, P.S. and BOSHOMANE, M.A.W. 2008. Land suitability assessment and precision farming prospects for irrigated maize-soyabea intercropping in Syferkuil experimental farm using geospatial information technology. *Journal of Agriculture and Social Research* 8: 138-147.

MZUKU, M., KHOSLA, R. REICH, R. INMAN, D., SMITH, F. and MACDONALD, L. 2005. Soil variability of measured soil properties across site-specific management zones. *Soil Science Society of America Journal* 69: 1572-1579.

NAJMADEEN, H.H., MOHAMMAD, A.O. and MOHAMED-AMIN H.H. 2010. Effects of soil texture on chemical compositions, microbial populations and carbon mineralization in soil. *The Egypt Society of Experimental Biology* 6: 59-64.

NATH, T. N. 2014. Soil bulk density and its impact on soil texture, organic matter content and available macronutrients of tea cultivated soil in dibrugarh district of Assam, India. *International Journal of Development Research* 4: 343-346.

NSANZABAGANWA, E., DAS, T.K., RANA, D.S. and KUMAR, S.N. 2014. Nitrogen and phosphorus effects on winter maize in an irrigated agroecosystem in western Indo-Gangetic plains of India. *Maydica* 59: 152-160.

ONTL, T.A. and SCHULTE, L.A. 2012. Soil carbon storage. Nature education knowledge 3 (10): 35. Available online at http://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790. Accessed on 05/03/2014

ÖZGÖZ, E. 2009. Long term conventional tillage effect on spatial variability of some soil physical properties. *Journal of Sustainable Agriculture* 33: 142-160.

PATEL, P.L., PATEL, N.P., PATEL, P.H. and GHAREKHAN, A. 2014. Correlation study of soil parameters of Kutch district agriculture land. *International Journal of Scientific and Research publications* 4: 1-5.

PAZ-GONZALEZ, A., VIEIRA, S.R. and TABOADA CASTRO, M.T. 2000. The effect of cultivation on the spatial variability of selected properties of an umbric horizon. *Geoderma* 97: 273-292.

PELLETIER, J.D. and RASMUSSEN, C. 2009. Geomorphically based predictive mapping of soil thickness in upland watersheds. *Water Resources Research* 45: 1-15.

PIERZYNSKI, G.M., LOGAN, T.J., TRAINA, S.J. and BIGHAM, J.M. 1990. Phosphorus chemistry and mineralogy in excessively fertilized soils: Quantitative analysis of phosphorus-rich particles. *Soil Science Society of America Journal* 54:1576-1583.

REZAEI, S.A. and GILKES, R.J. 2005. The effects of landscape attributes and plant community on soil physical properties in rangelands. *Geoderma* 125:145-154.

RHOTON, F.E. and LINDBO, D.L. 1997. A soil depth approach to soil quality assessment. *Journal of Soil and Water Conservation* 52: 66-72.

RUEHLMANN, J. and KÖRSCHENS, M. 2009. Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Science Society of America Journal* 73: 876-885.

SAGLAM, M., OZTURK, H.S., ERSAHIN, S. and OZKAN, A.I. 2011. Spatial variation of soil physical properties in adjacent alluvial and colluvial soils under Ustic moisture regime. *Hydrology and Earth System Science Discussions* 8: 4261-4280.

SCHOENEBERGER, P.J., WYSOCKI, D.A., BENHAM, E.C. and BRODERSON, W.D. 1998. Field book for describing and sampling soils. NRCS, USDA, National Soil Survey Center, Lincoln, NE.

SCHUMACHER, T.E., LINDSTROMB, M.J., SCHUMACHERC, J.A. and LEMME, G.D. 1999. Modeling spatial variation in productivity due to tillage and water erosion. *Soil and Tillage Research* 51: 331-339.

SCHWERTMANN, 1993. Soil color. Soil science society of America, Madison, WI.

SHAPIRO, S.S. and WILK, M.D. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52: 591-611.

SINGH, K., KUHAD, M.S and DHANKAR, S.S. 1989. Influence of soil characteristics on profile distribution of DTPA-extractable micronutrient cations. *Indian Journal of Agricultural Sciences* 59: 310-312.

SINGH, I.R., SHARMA, A.C. and Nr GOSWAMI, S. 2013. Nutrient status and their availability in relation to properties of soils of Koronivia, Fiji. *Fiji Agricultural Journal* 53: 1-6.

SIX, J., ELLIOTT, E.T. and PAUSTIAN, K. 2000. Soil structure and soil organic matter: II. A normalized stability index and the effect of mineralogy. *Soil Science Society of America Journal* 64: 1042-1049.

STONE, J.R., GILLIAM, J.W., CASSEL, D.K., DANIELS, R.B., NELSON, L.A. and KLEISS, H.J. 1985. Effect of erosion and landscape position on the productivity of Piedmont soils. *Soil Science Society of America Journal* 49: 987-991.

SWAROWSKY, A., DAHLGREN, R.A., TATE, K.W., HOPMANS, J.W. and O'GEEN, A.T. 2011. Catchment-scale soil water dynamics in a mediterranean-type oak woodland. *Vadose Zone Journal* 10: 800-815.

TORRENT, J., SCHWERTMANN, U., FETCHER, H. and ALFREZ, F. 1983. Quantitative relationships between soil colour and hematite content. *Soil Science* 136: 354-358.

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE. 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Pretoria, South Africa.

TSUI, C.C., CHEN, Z.S. and HSIEH, C.F. 2004. Relationships between soil properties and slope position in a lowland rain forest of southern Taiwan. *Geoderma* 123: 131-142.

UNITED STATES DEPARTMENT OF AGRICULTURE (NCRS), 2008. Soil quality indicators. Available online at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils /health/ assessment/?cid=stelprdb1237387. Accessed on 08/03/2014

UNITED STATES DEPARTMENT OF AGRICULTURE (NCRS), 2014. Soil physical and chemical properties. Available online at http://www.nrcs.usda.gov/wps/portal/ nrcs/detail/nj/home/?cid=nrcs141p2_018993. Accessed 18/02/2014

VANDEN HEUVEL, R.M. 1996. The promise of precision agriculture. *Journal of Soil and Water Conservation* 51: 38-40.

VAUGHAM, P.J., LESCH, S.M., CORWIN, D.L. and CONE, D.G. 1995. Water content effect on soil salinity prediction: A geostatistical study using cokriging. *Soil Science Society of America Journal* 59: 1146-1156.

VERMA, Y.K., SETIA, R.K., SHARMA, P.K., SINGH, C. and ASHOK, K. 2005. Pedospheric variations in distribution of DTPA-extractable micronutrients in soils developed on different physiographic units in central parts of Punjab, India. *International Journal of Agriculture and Biology* 7: 243-246.

VERVIER, P., PINHEIRO, A., FABRE, A., PINAY, G. and FUSTEC, E. 1999. Spatial changes in the modalities of N and P inputs in a rural river network. *Water Research* 33: 95-104.

VISCARRA ROSSEL, R.A., MINASNY, B., ROUDIER, P. and MCBRATNEY, A.B. 2006. Colour space models for soil science. *Geoderma* 133: 320-337.

WANG, Y.G., XIAO, D.N., LI, Y. and LI, X.Y. 2008. Soil salinity evolution and its relationship with dynamics of groundwater in the oasis of inland river basins: case study from the Fubei region of Xinjiang province, China. *Environmental Monitoring and Assessment* 140: 291-302.

WANG, Y.Q., ZHANG, X.C. and HUANG, C.Q. 2009. Spatial variability of soil total nitrogen and soil total phosphorus under different land uses in a small watershed on the Loess Plateau, China. *Geoderma* 150: 141-149.

WASKOM, R.M., BAUDER, J.G. and ANDALES, A.A. 2014. Diagnosing saline and sodic soil problems. Available online at http://www.ext.colostate.edu/pubs/crops/0051.html. Accessed on 24/03/2014

WEI, J.B., XIAO, D.N., ZENG, H. and FU, Y.K. 2008. Spatial variability of soil properties in relation to land use and topography in a typical small watershed of the black soil region, northeastern China. *Environmental Geology 53*: 1663-1672.

WEST, T.O. and POST, W.M. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal* 66: 1930-1946.

WILDING, L.P. 1985. Spatial Variability: It's Documentation, Accommodation and Implication to Soil Surveys. In: Soil Spatial Variability, Nielsen, D.R. and J. Bouma (Eds.). Pudoc, Wageningen, The Netherlands.

YEMEFACK, M., ROSSITER, D.G. and NJOMGANG, R. 2005. Multi-scale characterization of soil variability within an agricultural landscape mosaic system in southern Cameroon. *Geoderma* 125: 117-143.

ZHANG, S., YANG, X., WISS, M., GRIP, H. and LÖVDAHL, L. 2006. Changes in physical properties of a loess soil in China following two long-term fertilization regimes. *Geoderma* 136: 579-587.

ZHANG, C., LIU, S., ZHANG, X. and TAN, K. 2009. Research on the spatial variability of soil moisture. *Computer and Computing Technologies in Agriculture* 1: 285-292.

ZHANG, S., ZHANG, X., HUFFMAN, T., LIU, X. and YANG, J. 2011. Influence of topography and land management on soil nutrients variability in Northeast China. *Nutrient Cycling in Agroecosystems* 89: 427-438.

APPENDICES

Appendix1: Completely Randomized AOV for pH_{KCl}

Sources of variance	DF	SS	MS	F	P
Profile ID	21	18.4952	0.88072	101	0.0009
Error	44	0.3844	0.00874		
Total	65	18.8796			

Appendix 2: Completely Randomized AOV for pH_W

Sources of variance	DF	SS	MS	F	P
Profile ID	21	17.1090	0.81471	69.8	0.0056
Error	44	0.5133	0.01167		
Total	65	17.6223			

Appendix 3: Completely Randomized AOV for electrical conductivity

Sources of variance	DF	SS	MS	F	P
Profile ID	21	134318	6396.08	815	0.0860
Error	44	346	7.85		
Total	65	134663			

Appendix 4: Completely Randomized AOV for organic carbon

Sources of variance	DF	SS	MS	F	P
Profile ID	21	3.00231	0.14297	7.81	0.9109
Error	44	0.80567	0.01831		
Total	65	3.80798			

Appendix 5: Completely Randomized AOV for bulk density

Sources of variance	DF	SS	MS	F	P
Profile ID	21	1.28149	0.06102	97.8	0.2217
Error	44	0.02747	0.00062		
Total	65	1.30896			

Appendix 6: Analysis of Variance Table for Bray-1 phosphorus

Sources of variance	DF	SS	MS	F	P
Sdepth	1	450.000	450.000	42.86	0.0002
Error	8	84.000	10.500		
Total	21				

Appendix 7: Analysis of Variance Table for calcium

Sources of variance	DF	SS	MS	F	P
Sdepth	1	267424	267424	8.56	0.0191
Profile	12	1773659	147805	4.73	0.0175
Error	8	249788	31223		
Total	21				

Appendix 8: Analysis of Variance Table for electrical conductivity

Sources of variance	DF	SS	MS	F	P
Sdepth	1	8907.1	8907.12	6.71	0.0331
Error	8	10627.3	1328.41		
Total	21				

Appendix 9: Analysis of Variance Table for potassium

Sources of variance	DF	SS	MS	F	P
Sdepth	1	36090.9	36090.9	24.77	0.0011
Profile	12	63756.9	5313.1	3.65	0.0375
Error	8	11657.1	1457.1		
Total	21				

Appendix 10: Analysis of Variance Table for magnesium

Sources of variance	DF	SS	MS	F	P
Sdepth	1	233245	233245	35.55	0.0003
Profile	12	522505	43542	6.64	0.0060
Error	8	52491	6561		
Total	21				

Appendix 11: Analysis of Variance Table for manganese

Sources of variance	DF	SS	MS	F	P
Sdepth	1	480.500	480.500	44.28	0.0002
Profile	12	687.500	57.292	5.27	0.0126
Error	8	87.000	10.875		
Total	21				

Appendix 12: Analysis of Variance Table for sodium

Sources of variance	DF	SS	MS	F	P
Sdepth	1	27926.7	27926.7	22.52	0.0015
Error	8	9921.8	1240.2		
Total	21				

Appendix 13: Analysis of Variance Table for Organic carbon

Sources of variance	DF	SS	MS	F	P
Profile	12	0.85918	0.07160	4.75	0.0173
Error	8	0.12060	0.01508		
Total	21				

Appendix 14: Analysis of Variance Table for Zinc

Sources of variance	DF	SS	MS	F	P
Sdepth	1	2.86402	2.86402	26.74	0.0009
Error	8	0.85698	0.10712		
Total	21				

Appendix 15: Analysis of Variance Table for pH_W

Sources of variance	DF	SS	MS	F	P
Sdepth	1	1.88827	1.88827	9.31	0.0158
Error	8	1.62188	0.20273		
Total	21				

Appendix 16: Analysis of Variance Table for effective cation exchange capacity

Sources of variance	DF	SS	MS	F	P
Sdepth	1	46.433	46.4327	23.06	0.0014
Profile	12	168.722	14.0601	6.98	0.0051
Error	8	16.106	2.0132		
Total	21				

Appendix 17: Descriptive Statistics for surface soil samples

Variable	Mean	SE Mean	Skewness
Ca (mg/kg)	716.58	63.266	0.0661
Cu (mg/kg)	1.5567	0.0669	-0.2458
EC (µS/cm)	61.999	6.7538	1.0593
Fe (mg/kg)	12.530	1.2393	1.2260
K (mg/kg)	142.00	22.131	0.8261
Mg (mg/kg)	428.00	36.553	-0.0116
Mn(mg/kg)	33.000	1.9848	0.6223
Na (mg/kg)	39.333	8.5859	1.1347
OC (%)	0.5808	0.0650	0.010
Bray-1 P (mg/kg)	12.833	1.4504	-0.7870
Zn (mg/kg)	1.3850	0.1235	-0.7856
pH_W	7.5208	0.1275	-0.1659
pH_{KCl}	6.4558	0.1458	-0.6146
S-Value	7.6558	0.6603	-0.0752

Appendix18: Descriptive Statistics for sub-surface soil samples

Variable	Mean	SE Mean	Skewness
Ca (mg/kg)	989.20	128.89	1.0879
Cu (mg/kg)	1.7440	0.0451	-0.0571
EC (µS/cm)	104.56	17.910	1.1698
Fe (mg/kg)	14.188	1.3817	-0.7730
K (mg/kg)	70.000	10.934	1.1673
Mg (mg/kg)	665.70	66.552	-0.2829
Mn (mg/kg)	23.500	1.6816	0.3739
Na (mg/kg)	119.80	17.995	-0.3987
OC (%)	0.6590	0.0685	0.0003
Bray-1 P (mg/kg)	1.4000	0.2211	1.3979
Zn (mg/kg)	0.4880	0.0495	0.4415
pH_W	8.0600	0.1476	-0.7325
pH_{KCl}	6.7370	0.1809	0.0556
S-Value	11.147	1.1892	0.1422

Appendix19: Selected pictures of soil profiles dug in the research block

Plate 1: Typical shallow soil profiles found in the research block at the University of Limpopo experimental farm, Syferkuil

Appendix 20: Accepted abstract for poster presentation at the January 2014 Combined Congress

PHYSICO-CHEMICAL CHARACTERISATION OF SOILS IN THE RESEARCH BLOCK AT UNIVERSITY OF LIMPOPO EXPERIMENTAL FARM, SYFERKUIL, LIMPOPO PROVINCE

Phefadu KC*, Kutu FR, Vanassche FMG

University of Limpopo, Department of Plant Production, Soil Science and Agricultural Engineering, Private Bag X1106, Sovenga, 0727
**Author email address: kphefadu88@gmail.com*

INTRODUCTION

Agricultural sustainability depends largely upon improvements in soil physical, chemical and biological properties. Understanding the in-field distribution and nature of soil properties is essential in refining agricultural management practices while minimizing environmental damage. Soil characterisation provides detailed information about the soil spatial variability within a given land area; and thus allows for the implementation of appropriate crop and soil management practices that align with the soil condition.

OBJECTIVE

To investigate the spatial variability of the soil of the research block at the University of Limpopo Experimental Farm, Syferkuil.

MATERIALS AND METHODS

The study was conducted at the University of Limpopo Experimental Farm, Syferkuil (23°50'36.86"S and 29°40'54.99"E). Twelve profile pits were dug across the research block at selected areas. Soil sample was collected from each diagnostic horizon for every soil profile and analysed for selected soil physical and chemical properties using standard analytical procedures. Soil depth, structure and consistency were documented in the field. Data generated were subjected to classical statistical methods to obtain the minimum, maximum, mean, median, skewness (Shapiro and Wilk, 1965), and standard deviation at each horizon (n = 22). A one way analysis of variance was also performed using Statistix 8.1 to compare each variable across the soil profiles using LSD test at 5%.

RESULTS AND DISCUSION

The depth of the profiles ranges from 0.28 m to 1 m and this was categorized as shallow soils. The soil colour (dry) varies from dark brown to very dark greyish brown. The structure and consistency of the soil were predominantly blocky and firm/friable respectively; while the bulk density values for the soil samples were fairly similar. The sand, silt and clay of the samples fall in the range 61-87%, 1-15% and 7-27%, respectively; and are broadly categorised as sandy loam, loamy sand and sandy clay loam. The pH (water)of all the soil samples ranged from slightly alkalinity to moderately acidic. Electrical conductivity, Bray P1, exchangeable K, Ca, and Mg, extractable Mn, Na and Zn as well as S-value differ significantly ($p<0.05$) with depth while percent OC and S-value differ significantly ($p<0.05$) across soil profiles. The coefficient of variation values of 21.7-45.8% were obtained for electrical conductivity, Bray P1, exchangeable K, Ca and Na as well as extractable Fe and Zn. The majority of the chemical parameters evaluated were highly skewed with a coefficient of skewness generally greater than 0.5 indicating that their distribution is not normally distributed.The observed variation among the soil physical and chemical properties may be a result of land uses or natural factors such as climate.

CONCLUSION

There exist a fairly high level of spatial variability of soil physico-chemical properties across the research block; and the soils are generally shallow. Of all the measured parameters, electrical conductivity, Bray P1, exchangeable K, Ca and Na as well as extractable Fe and Zn showed a huge percent variation across the profiles, which is a clear indication of the heterogenic nature of soil. This study provided quantitative information for monitoring changes in soil properties and improving soil management practices on the research field.

REFERENCE

SHAPIRO, S.S. and WILK, M.B. 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52: 591-611.