SPATIAL VARIABILITY OF SOIL BIOLOGICAL AND CHEMICAL INDICATORS IN SELECTED SOILS IN SOUTH AFRICA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS SCIENCE IN AGRICULTURE (SOIL SCIENCE) AT THE UNIVERSITY OF VENDA

BY

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DEDICATION

This thesis is dedicated to my parents, my sister Iva, and my brothers Mashao, Oupa, and Tumelo and my fiancée Kedibone Surprise for their extrovert support.

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DECLARATION

I, Khutso Lenyanyabedi declares that: The research reported in this thesis, except where otherwise indicated is my original work. This thesis has not been submitted for examination for any degree at any other university. This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from the other person. This thesis does not contain other person's writing, unless specifically acknowledged as being sourced from other researches. Where other written sources have been quoted then: (a) their words have been re-written, but the general information attributed to them has been referenced. (b) Where their exact words have been used then their writing has been placed in italics and inside quotation marks and referenced.

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Khutso Lenyanyabedi

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LIST OF SYMBOLS AND ABBREVIATIONS

FAO-Food and Agriculture Organisation

RPM-Revolution per minutes

ABSTRACT

Understanding the spatial variability of selected soil fertility indicators could make it possible to optimize the use of agricultural inputs with the reduction of economic and environmental risks. The aim of this study was to determine the degree of spatial variability of soil fertility indicators in selected soils in South Africa. There is a paucity of information on the spatial variability of soil fertility indicators in many part of South Africa. Soil samples were collected from two sites viz. University of Venda and Roodeplaat Experimental Farms. The fields were demarcated into 20 m × 20 m grid cells in approximately~1 ha using a measuring tape. Hence, the field consisted of ~12 grids. Therefore, soil samples were collected from 0 - 0.2 m depth at both sites and the coordinates of each sampling points were recorded with GPS. Then, soil respiration, cellulolytic, catalase, urease, acid phosphatase, organic carbon and total nitrogen, cation exchange capacity, soil pH and soil texture were determined using standard methods. Descriptive and geostatistical analyses were performed using ArcMap® version 9.0. The results showed that most parameters were analysed by exponential model except for acid phosphatase and organic carbon that fitted into Gaussian models in University of Venda Experimental Farm. Spatial dependence of the soil respiration, cellulases and organic carbon have strong spatial dependence with nugget to sill ratios of less than 25% in the field of University of Venda Experimental Farm. Thus, catalase, acid phosphatase and organic phosphorus exhibited moderate spatial dependence with nugget to sill ratios between 25 and 75%. All parameters were analysed by exponential model except cellulases in Roodeplaat Experimental Farm. Hence, all parameters exhibited strong spatial dependence (nugget/sill ratio < 25%) except acid phosphatase and cellulases that were exhibited moderate (nugget/sill ratio 25 and 75%) and weak (nugget/sill ratio >75%) spatial dependence, respectively. The measured parameters were spatial dependent at Roodeplaat Experimental Farm more than in University of Venda Experimental Farm. Hence, spatial dependence of measured parameters at Roodeplaat Experimental Farm mainly controlled by extrinsic factors than intrinsic factors. The study showed that geostatistics is a useful tool to map spatial variabilities of soil fertility indicators under arable lands. Heterogeneity and variation

of soil fertility indicators in a field due to intrinsic and extrinsic factors should be taken into consideration for a successful agricultural management.

Key words: Soil enzymes, physico-chemical properties, semivariograms, Kriging, spatial dependence.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Solis are intrinsically heterogeneous in nature and their properties continuously change in time and space (Kavianpoor *et al*., 2012). Furthermore, Soils are diverse and dynamic. Soil variability is attributed to the interaction heterogeneity of intrinsic factors (Nourzadeh *et al*. 2012) and extrinsic factors (Laekemariam *et al*. 2016). For instance, the interaction of natural factors such as climate and topography affected nutrient availability and their distribution within and across the fields (Manyevere *et al*., 2017). Consequently, soil heterogeneity can lead to under/over fertiliser applications within/across (Ferguson *et al*., 2002). Therefore, understanding soil spatial variability of soil fertility indicators could be necessary for the implementation of management practices that are environmentally friendly. Moreover, soil spatial variability is crucial for the development of site-specific nutrient management. Hence, site-specific nutrient management has three benefits, namely increasing nutrients input efficiency, improving the economic margins of the crop productivity and minimizing environmental risk (Singh *et al*., 2010).

Changes in soil physical, chemical and biological indicators must be taken into accounts when evaluating soil fertility (Sherene, 2017). However, the current study focused on soil biological and chemical indicators. Biological and chemical soil indicators are quick to change due to natural and anthropogenic factors. Spatial variability of soil properties at field and time scale is important for making decisions relating to soil fertilization for sustainable crop production (Bai and Wang, 2011). Laekemariam *et al*., (2018), Nethononda *et al*., (2013) assessed spatial variability of soil properties on a large scale more than 100hectares. Bhunia *et al*., (2018) assessment of spatial variability of soil properties on 45 hectares using geostatistical approach of lateritic soil in West Bengal, India under Lateritic and younger alluvial soils.

Spatial variability of soil biological and chemical properties under different ecosystems have been analysed by different researchers across the world. Although such studies provide information on the soil variability at larger spatial scale. Hence, few studies assessed the spatial variability of soil properties on a small scale (Qiu *et al*., 2011; Aisha *et al*., 2010). There is a paucity of Information on the spatial variability of soil fertility indicators in University of Venda and Roodeplaat Experimental Farms. Thus, necessitated this study. Therefore, objective of this study was to evaluate the degree of spatial variability of soil biological and chemical indicators using geostatistics to provide information for better soil fertility management.

1.2 Problem Statement

Soil properties exhibit spatial variability, but little evidence exists about soil fertility indicators. The spatial dependence is completely ignored despite the crucial role it may play in the behaviour of soils. In many parts of South Africa, cultivated fields are treated as homogenous. The consequence of treating cultivated fields as homogenous is associated with low economic returns as well as adverse environmental issues because of unaccounted spatial variability.

1.3 Justification

The study of soil fertility is ancient and has hitherto focused on the nutritive substances for plants. Such studies are costly and time consuming. Detailed knowledge of soil fertility indicators can contribute to advances in precision soil management and agronomic practices for sustainable use. Knowledge of spatial soil fertility indicators could make it possible to optimize the use of agricultural inputs with the reduction of economic and environmental risks. In addition, this could also be important for refining existing soil fertility management practices.

1.4 Aim of the study

To use biological and chemical indicators to quantify soil fertility and their spatial dependence in South African soils.

1.5 Objectives

1.5.1 To measure soil biological and chemical indicators of soil fertility in selected South African soils.

1.5.2 To determine the degree of spatial variability of biological and chemical indicators of soil fertility in selected South African soils.

1.6 Hypothesis

1.6.1 There is no spatial dependence of soil fertility indicators in selected soils.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Indicators of Soil Fertility

In the beginning of 20th century, evaluation of soil fertility was established and later in the second half of 20th century farmers, agro-chemist and agro-phyto-technics has been evaluating it according to crop size (Obrisca *et al*., 2010). According to Sherene (2017), changes in physical, chemical and biological soil properties must be consider into accounts when evaluating soil fertility. For instance, Oliver *et al*., (2013) measured soil pH, electrical conductive ad nutrients measured as indicators of soil fertility in agro ecosystem. Spatial variability of soil fertility indicators has received a considerable attention in many part of the world. Knowledge of spatial variability is a pre-requisite for site-specific management development (Patil *et al*., 2011; Sharma *et al*., 2011). Understanding of spatial variability of soil properties is necessary for proper nutrient management (Nethononda *et al*., 2012). Spatial variability is achieved through the use of Geo statistical methods. Geo-statistics is extensively used to characterize the spatial variability of soil attributes due to its ability of quantifying and reducing sampling uncertainties and minimizing investigation costs (Cambule *et al*., 2014).

The nugget/sill ratio can be used as criteria to classify the strength to the spatial dependence of soil properties. The nugget/sill ratio <25% indicate strong spatial dependency, between 25 and 75% moderate spatial dependency and >75% weak spatial dependency (Cambardella *et al*., 1994, Shi *et al*., 2008). The Nugget/Sill higher ratio indicates that the spatial variability is primarily caused by stochastic factors, such as fertilization, farming measures, cropping systems and other human activities. The lower ratio suggests that structural factors, such as climate, parent material, topography, soil properties and other natural factors, play a significant role in spatial variability (Venteris *et al*., 2014)

2.1.1 Soil Respiration

Soil respiration is the second-largest terrestrial carbon flux in the world (Davidson *et al*., 1998). Hence, it has been regarded as an important of soil fertility indicators (Staben *et al*., 1997, Haney *et al*., 2008). This could because soil respiration reveals information regarding the levels of microbial activity and its contents as well as decomposition rate of soil organic matter. For instance, soil respiration is proportional to the soil organic carbon, dead roots, exudates and recently dead microbes; however, the proportions of soil organic matter also affect it, because they normally differ with regard degree of oxidation. Soil respiration is regulated by inherent soil properties (e.g., microbial communities, organic carbon content, water content and nitrogen content) and climatic factors all at different spatial and temporal scales (Vincent *et al*., 2006; Webster *et al*., 2008; Moyano *et al*., 2013). For instance, Makhado 2011 determined of soil respiration in a semi-arid savanna ecosystem, Kruger National Park, South Africa and observed low soil respiration at much higher temperature and low soil moisture. Soil moisture content is the main controlling factor for soil respiration, especially in a warm, semi-arid environment (Zhang *et al*., 2003).

2.1.2 Soil Enzymes

Soil enzymes play a key role in the energy transfer through decomposition of soil organic matter and nutrient cycling. Hence, play an important role in agriculture. For instance, Urease is an extracellular enzyme that catalyses the hydrolysis of urea into ammonia and carbon dioxide (Tabatabai, 1982; Das and Varma 2011). Other important soil enzymes include hydrolase, which is responsible for organic matter breakdown, while phosphatase take part in the transformation of organic phosphate into inorganic phosphate (Makoi and Ndakidemi, 2008).

Soil enzymes serves as sensitive indicators of soil fertility (Nannipieri *et al*., 2002; Fließbach *et al*., 2007). Henceforward, they respond quickly due to anthropogenic (management practices, land use type and fertilisation and natural factors (soil types,

soil forming processes, topography and climate) (Nannipieri *et al*., 2012; Kumar *et al*., 2013). For instance, Błońska *et al*., 2017 investigated the relationship between soil properties, enzymes and land use in Cambisols and Arenosols of the southwestern and central Poland, in the Forest Districts. Their result showed that the activities of dehydrogenases and ureases were high in forest soils, which were characterised by high accumulation of organic matter than in the soils used for crop cultivation. They concluded that high enzyme activity of pastureland is due to the effects of vegetation and lack of tillage. Udawatta *et al*. 2008 reported that variability in litters affects enzyme activities and enzyme activities are higher in the areas with litters. Kizilkaya and Dengiz 2010 support this result and indicate that there is a positive correlation between urease enzyme activity and organic matter. This concur with the results reported several authors, the urease activities were higher followed by this order natural forest > shrubbery > grassland > slope field into terrace > rock desertification > farmland (Kong *et al*. 2007, Liu *et al*., 2008). Furthermore, Wang *et al*. 2012 identified the effect of the type of vegetation on urease enzyme activity in their studies and stated that the highest urease enzyme activity was determined in areas covered with Caragana Korshinskii and the lowest urease enzyme activity was found in meadows. Therefore, the urease activity is directly related to type of vegetation and quality of incorporated organic materials, soil organic matter and microbiological activities in the soils (Stott and Hagedon, 1980; Alef and Nannipieri 1995).

Acosta-Martinez *et al*., 2007 Studied on the enzymes activities as affected by soil properties and land use revealed higher acid phosphatase activity under agriculture soil as compared to pasture in Oxisols and Ultisols than in Inceptisols of Rio Grande de Arecibo watershed located in the north-central part of Puerto Rico. Hence, they reported lowest pH in Oxisols (4.5), Ultisols (4.9) and Inceptisols (5.3), respectively. In generally, Oxisols and Ultisols are two tropical soil orders, which are characterized by high acidity and low fertility. The activity of the acid phosphatase is related with soil acidity. For instance, as the soil pH decreases, the activity of the acid phosphatase increases, while alkaline phosphatase decreases (Dick *et al*., 2000). Moreover, in contrary, Gonnety *et al*., 2012 investigated effects of land use, soil types and chemical properties on the enzymatic activities. They reported higher acid

phosphatase under Chromolaena odorata fallow with high pH, C, N, mg^{2+}, K^{+}, CEC except phosphorus than in Maize crop in the semi-deciduous forest areas of the Central-West Côte d'Ivoire under Ferralsols. In phosphorus deficient soils, acid phosphatase secretion from plant roots increases to enhance phosphate availability to plants (Li *et al*., 1997; Hayes *et al*., 1999; Nannipieri *et al*., 2011). They concluded that the activities of the soil enzymes, generally decreased with increased anthropogenic activities.

Li *et al*., 2014 studied the effect of land use on soil enzyme activities at karst area in Nanchuan, Chongqing, South-West China. They recorded higher and lower values for catalase activity in the slope filed into terrace and natural forest, respectively. In the case of urease activity, the highest and lowest values were reported in artificial forest and farmland, respectively. However, the physiological function and regulation of catalase in the soils are still poorly understood. Kravkaz Kuscu *et al*., 2018 investigated the relationship between enzyme activity (urease-catalase) and nutrient element in soil use (Agriculture, pasture and forest). They noted a remarkable relationship between urease and catalase. The highest values in terms of urease and catalase enzymes, Ca and Zn nutrient elements were noted in forest soils and the lowest values are obtained from pasture soils. Shi *et al*. 2008 studied enzyme activities of urban soils under different land use in the Shenzhen city, China. The highest activity of catalase was reported in urban park soils. They have observed that soil electrical conductivity had a positive direct effect on activities of catalase and there was a significant correlation between soil electrical conductivity and catalase. In addition, catalase is an important indicator of soil fertility and aerobic microorganisms (Burns, 1982) and it decomposes peroxide into water and oxygen. Its activity depends from organic oxygen concentration, microbe biomass, changes in CO_2, and depends from dehydrogenase, amidase, glucosidase and esterase activity in soils (Purev *et al*., 2012).

Kanazawa and Miyashita 1987 studied cellulase activity in Forest Soils of the on the Southern slope of Mt. Shiga located at Shigakogen, Shimotakai-gun, Nagano Prefecture and Japan. They reported highest activity of cellulase in the L horizon in

the Wet Humus Podzolic Soil (Pwh) soil and in the F horizon in the (Alpine Brown Forest Soil) BD soil. Hence, it decreased with the increase of depth in the horizon and found to be highly correlated with the cellulose content, microbial respiration, hyphal length, and enzyme activity (P-glucosidase, p-acetyl glucosaminidase, proteinase). Generally, Cellulases are a group of enzymes that catalyse the degradation of cellulose, polysaccharides (Deng and Tabatabai, 1994). For example, carbon to be released as an energy source for use by the micro- organisms, cellulose in plant debris has to be degraded into glucose, cellobiose and high molecular weight oligosaccharides by cellulases enzymes (White, 1982).

2.1.3 Physico-Chemical Properties

Soil physico-chemical properties are regarded as basic indicators for estimating the level of soil nutrients (Zhao *et al*., 2018). Physical and chemical soil properties are important in soil fertility evaluation because they are correlated with hydrological processes and capacity to provide nutrients for plant/crop growth, respectively (Schoenholtz *et al*., 2000). The main physical properties that have been used as indicators includes texture, bulk density, porosity, and aggregate stability. On the other hand, among chemical properties pH, buffering capacity, cation exchange capacity, total nitrogen, available phosphorus, potassium and various micronutrients have been used as indicators in other agriculture systems (Oliver *et al*., 2013).

Molepo *et al*., 2017 studied physicochemical, geochemical and mineralogical Aspects of Agricultural Soils (uncultivated, cultivated and grazing land) of University of Limpopo Province, South Africa. Their results showed that the highest pH levels were noted in uncultivated fallow land (7.0-8.3), intensively cultivated land (7.3-7.7) and grazing land (6-7), respectively. Hence, the highest electrical conductivity values were noted in grazing land (6-85 µS/cm) than in intensively cultivated (12-43 µS/cm) and grazing uncultivated fallow land (13-42 µS/cm), respectively. Similarly, Tegenu *et al*., 2008 assessed soil properties and fertility status dynamics of North Western Ethiopia as Influenced by land Use changes and they found that soil pH values were high in forest land and low in grazing land. However, highest organic carbon and

total nitrogen were reported in forest than in other land use. Moreover, these results are consistent with the study conducted by Muche *et al*., 2015 in terms of organic carbon and total nitrogen, however they reported pH value in cultivated land (5.0) as compared to other land use including grazing land (5.2). Low pH in the cultivated land could due to poorly managed cultivation, inappropriate use of the ammonium-based fertilisers and accelerated erosions (Nega and Heluf, 2013). Soil pH helps in maintaining soil fertility and it also helps in ensuring the availability of the plant nutrients (Deshmukh, 2012).

Phosphorus exists in soil in either inorganic or organic forms. Organic P forms occurs in soil mainly as inositol phosphates, phospholipids, and nucleic acids and can be a potential source of P for plants and microorganisms only after hydrolysis (Turner and Haygarth 2005; Wang *et al*. 2011). Acid and alkaline phosphatase are two extracellular phosphomonoesterases that hydrolyze the ester–phosphate bonds in soil organic P, which releases phosphate into the soil solution for uptake by plants and microorganisms (Nannipieri *et al*. 2011). For instance, Pandey *et al*., 2014 found that tillage reduces the activity of acid phosphatase, hence reduced the biological activity of surface soils and phosphorus nutrient cycling processes in the soil. Nitrogen containing fertilization increased acid phosphatase activity and reduced alkaline phosphatase activity in soils cultivated with corn and wheat (Kalembasa and Symanowicz, 2012; Lemanowicz, 2011).

2.2 Spatial Variability of Soil Fertility indicators

2.2.1 Spatial variability of soil respiration

Spatial variability of soil respiration has been carried out on the flatland (FoÂ ti *et al*., 2016) and on the hill slope ecosystem. Spatial variability of soil respiration is driven by texture, total soil organic carbon, distribution of organic matter and quantities of soil carbon pools (Fang *et al*., 1998; Hanson *et al*., 2000; Klopatek, 2002). For instance, Sun *et al*., 2018 studied spatial variations of soil respiration and temperature sensitivity along a steep slope of the semiarid Loess Plateau and

observed greater soil respiration at the lower slope position which is characterised by greater soil moisture, root biomass, carbon and nitrogen contents. They concluded that soil respiration was enhanced by the greater soil moisture, root biomass, carbon and nitrogen contents at the lower slope position than at the upper slope position. Similarly Saiz *et al*., 2006 assessed seasonal and spatial variability of soil respiration in four Sitka spruce stands and found that greater soil respiration was at the points with higher accumulation of organic matter. Stoyan *et al*., 2000 assessed spatial heterogeneity of soil respiration and related soil properties at the plant scale under poplar and wheat cropping system and observed that more concentrated soil respiration close to the tree trunk could be associated with higher moisture content and plant derived carbon.

2.2.2 Spatial variability of soil enzymes

Askın and Kızılkaya, 2005 assessed spatial variability of soil enzyme activities in pasture topsoils on the Karaköy State Farm in the Black Sea region of northern Turkey. Hence they observed strong spatial dependence for alkaline phosphatase activity and arylsulfatase activity, while moderate spatial dependence for urease activity. The activity of urease was positively correlated with soil organic matter, whereas alkaline phosphatase activity and arylsulfatase were positively correlated with pH, cation exchange capacity (CEC), lime, and silt content. They concluded that the spatially different distribution of the enzymatic activity is related to the variations in soil OM content, the activity of related living organisms, and the intensity of biological processes.

Tan *et al* 2014 studied county-scale spatial distribution of soil enzyme activities and enzyme activity indices in agricultural land of Changwu County, which is located in Xianyang City, Shaanxi Province, China. They reported that semi variance for the soil phosphatase (12.99km), urease (9.36km), catalase (5.33km), invertase (3.89km) and dehydrogenase (1.99km) activities exhibited spatial correlated with distance that ranged from 2 to 13km. Hence, the nugget to sill ratios descended in the order of

urease activity (85%) > dehydrogenase activity (71%) > phosphatase activity (61%) > invertase activity (60%) > catalase activity (54%). Consequently, invertase, phosphatase and catalase were moderately spatially correlated, whereas urease and dehydrogenase exhibited weakly spatially correlated. Moreover they observed patchy distribution and highest activities for invertase, urease, catalase activities OM, total N, total P, and CEC in the northern part of Changwu, while the alkali-hydrolyzable N, available P, available K, and soil pH levels were relatively low in the northern part of Changwu. In the case of soil enzymes, they concluded that the moderate spatial dependence of invertase, phosphatase, dehydrogenase, and catalase activities indicates that these enzyme activities could be primarily controlled by specific geological factors, whereas the weak spatial dependence of soil urease activities indicates that the environment has a stronger impact than geographical distance on the spatial distribution of relevant microbial communities.

Recently, Piotrowska-Długosz *et al*., 2016 studied spatio-temporal variations of soil properties in a plot scale on a 0.4-ha of Orlinek near Mrocza in the Pomerania and Cuiavia region in northwest Poland. Then they observed that the semi variance for acid and alkaline phosphatase in August and April as sampling months the range distance ranged from 25.0 to 35.0m. Hence the acid phosphatase exhibited moderate spatial dependence in both sampling months and on the other hand, alkani phosphatase showed strong in April and moderate spatial dependence in August. Then the highest values of acid phosphatase in August were observed in the northeast corner of the area, while the lowest was located in the northwest part of the field. On the other hand, the highest activity of alkaline phosphatase was located along the western part of the field and alkaline phosphatase was positively related with soil pH_{Kcl} and acid phosphatase was negatively related. The activities of soil alkaline and acid phosphatase are closely related to soil pH, with acid phosphatase dominating in acid soils and alkaline phosphatase in alkaline soils (Nannipieri *et al*. 2011). They concluded that variation in soil pH in both sampling months could be a possible source of the variability of soil phosphatases.

Piotrowska *et al*., 2011 studied field-scale variability of topsoil dehydrogenase and cellulases activities as affected by variability of some physico-chemical properties on 50 hectares of northern Poland. They found that all semivariograms exhibited a spatial structure and spherical models provided the best fit for organic carbon content and total nitrogen contents, dehydrogenase activity and clay percentage, while spherical/linear models described cellulase activity and soil pH. Hence, cellulases activity exhibited a weak spatial dependence, whereas all other parameters exhibited strong spatial dependence. Weak spatial dependent parameters might be controlled by application of fertilizers and tillage, whereas strong spatial dependent parameters might be influenced by variations in soil characteristics, such as texture and mineralogy (Cambardella *et al*., 1994).

2.2.3 Spatial variability of Physico-Chemical Properties

Phefadu and Kutu, 2016 evaluated of spatial variability of soil physico-chemical characteristics on Rhodic Ferralsol at the Syferkuil experimental farm of University of Limpopo, South Africa. In their study they measured semi-variogram parameters for the following soil variables pH, electrical conductivity, organic carbon, clay, sand and bulk density for soil samples collected from top and sub soil layers. According to their results based on nugget to sill ratio, topsoil EC, OC and sand and subsoil BD were strongly spatially dependence and topsoil clay content, and pH exhibited moderate, while subsoil pH, EC and sand exhibited weak spatial dependence. Soil organic carbon had strong spatial dependence similar to what had been illustrated in the research of Tagore *et al*., (2014). Therefore, they concluded that the spatial variability of physico-chemical properties of the soil is associated with the land use and management practices.

Kavianpoor *et al*., 2012 studied spatial variability of some chemical and physical soil properties in Nesho Mountainous Rangelands on 6 hectares area, land use was forest. Nitrogen, phosphorus, sodium, magnesium, and sand exhibited weak spatial dependence and organic matter, bulk density, particle density, electrical conductivity and clay showed moderate, while $CaCO_3$, available potassium, pH, calcium, silt and saturated moistures had strong spatial dependence based on nugget to sill ratio. In

the case of soil pH, this result correspond with the once reported by Weindorf and Zhu, (2010) who reported strong spatial dependence for soil pH.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Sites and Soils

The soil samples were collected from two sites namely University of Venda (Site 1) and Roodeplaat Experimental Farms (Site 2). Figure 1 shows maps of the two study sites.

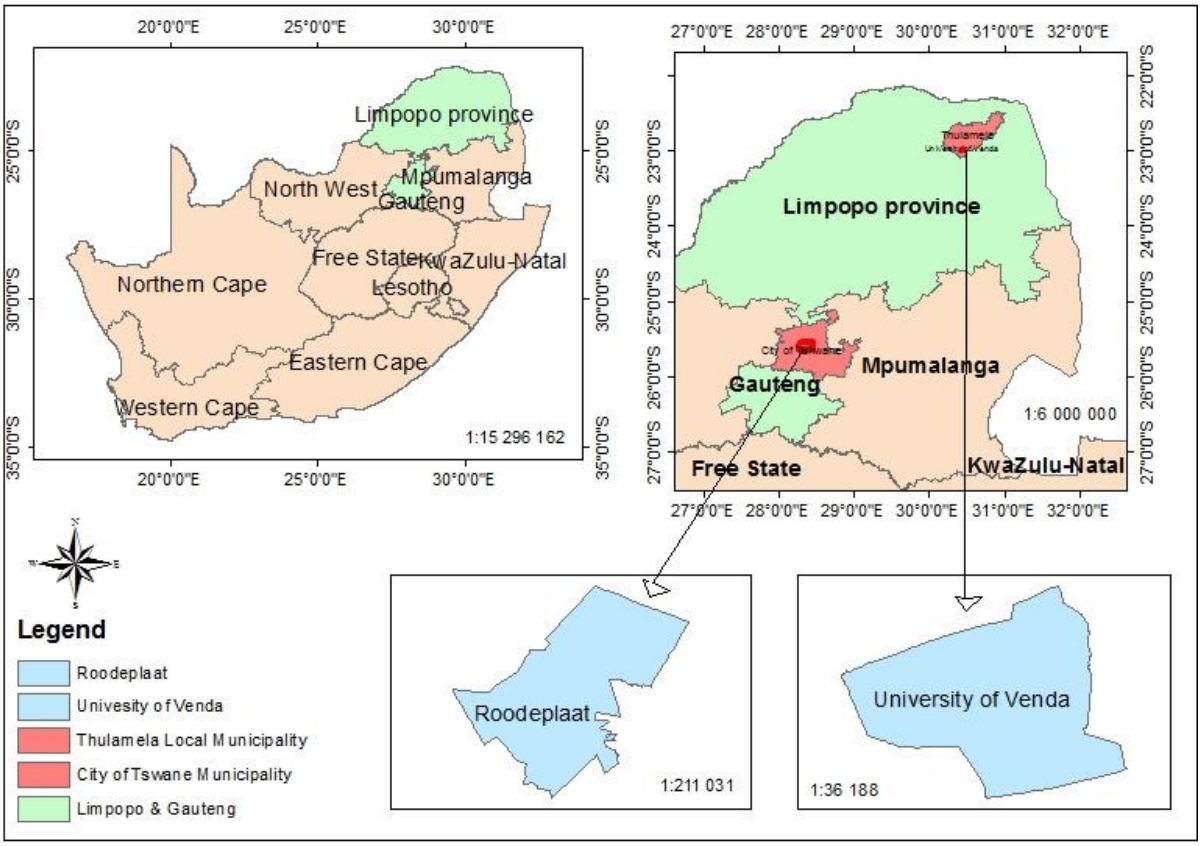


Figure 1. Map of the two study sites at University of Venda Experimental Farm and ARC-VOPI Roodeplaat

University of Venda Experimental Farm.

The University of Venda experimental farm is in Thohoyandou, Limpopo, South Africa. It is located at 22°58´S and longitude of 30º26´E with an elevation of ~596 m above sea level (Mzezewa and Van Rensburg 2011). The daily temperatures at Thohoyandou vary from about 20°C to 30°C in summer and between approximately 12°C and 26°C in winter. Rainfall is highly seasonal with 95% occurring between October and March, often with a mid-season dry spell during critical periods of crop growth (Food and Agriculture Organisation, 2009). The soils at the University of Venda experimental farm are red and deep (≥0.15m), well drained. The soils are red apedal structure and formed in situ. They are classified locally as Hutton form (Soil Classification Working Group, 1991) equivalent to Rhodic Ferralsol (WRB, 2006). The site has been only used for animal grazing.

Roodeplaat Experimental Farm.

Roodeplaat Experimental Farm of the Agricultural Research Council, Vegetable and Ornamental Plants in Pretoria, Gauteng Province, South Africa. It is located between 25.6014° S and 28.3603° E with an elevation of ~1168 m above sea level. The farm is characterized by sandy clay loam soil classified as Clovelly soil form (Soil Classification Working Group, 1991) or Cambisols / Luvisols (FAO, 2016) and continuously used for agricultural research purposes. The area has a humid subtropical climate with summer rainfall with an average of about ~650 mm per annum. Daily temperature ranges between 8–34°C in summer and 4–23°C in winter (Beletse, 2013). The site has been used to grow sweat potatoes for a decade. NPK

fertilisers and Grazon herbicides were the only chemical used to improve soil fertility status and destroy weeds, respectively.

3.2 Field Preparation and Layout

The fields were demarcated into 20 m × 20 m grid cells in approximately~1 ha using a measuring tape. Hence the field consisted of ~12 grids. Figure 2 shows the sketch of the layout at the two sites. Prior to sampling of the soils, both sites were conventional tilled using a disc plough and harrow.

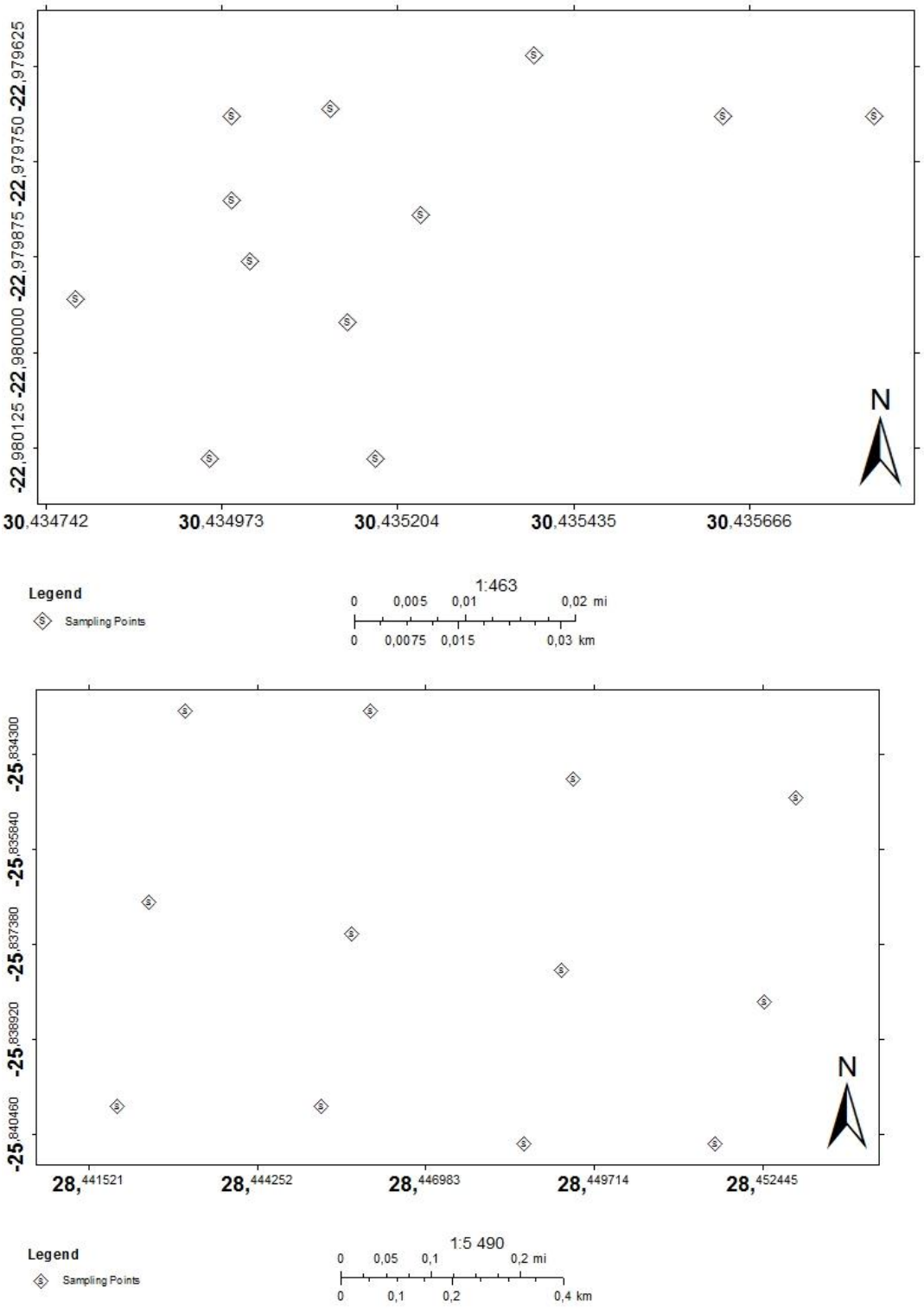


Figure 2. Sketch of the field layout at University of Venda (top) and Roodeplaat Experimental Farms (bottom)

3.3 Soil Sample Collection and Laboratory Analysis

Twenty-four soil samples were collected in the 20 m × 20 m grid cells with 12 sampling points across the ~1 ha at 0 – 0.2 m depth using soil auger. Soil samples at University of Venda and Roodeplaat Experimental Farms were collected at the beginning of April and July 2018, respectively. Before soil sampling, all litters were carefully removed from the auger positions. Coordinates of the sampling points were recorded using the Global positioning system (GARMIN GPSMAP 60_{cx} MODEL). Soils were collected at the centre of the mesh point and the samples that are around the centre point about 20 m away and were mixed thoroughly to make a composite sample for one grid cell (Li *et al*., 2013). The soil samples were then transported to the laboratory for analysis. Prior to analysis, soil samples for biological indicators were kept in the refrigerator at 4°C until analysis. On the other hand, soil samples for chemical indicators were air dried at room temperature for a week and sieved through a 2-mm sieve. All the analyses were done in triplicate.

3.3.1 Biological properties

Soil Respiration

Soil respiration was measured using modified alkali trap method by (Danga *et al*., 2013). This method is based on the measurement of CO_2 released during the microbial activity in the soil. 20 g of soil was placed in a sealed bottle. A 10 mL vial bottle containing 5 mL solution of 1 M NaOH was placed inside the sealed bottle and incubated for 24 hours at room temperature. At the end of incubation period, three drops of the phenolphthalein indicator were added to the 1 M NaOH solution. For blank, 10 mL vial containing 5 mL was incubated in a sealed bottle without soil. Prior titration, a solution of $BaCl_2$ (2.0 mL) of a 30% (*w*/*v*) was added to both volumetric flasks for sample and blank to precipitate the CO_2 as $BaCO_3$. The 1 M NaOH solution was titrated against 1 M HCl and the endpoint of the titration was when the pink colour changed to pale. The amount of carbon dioxide was calculated from the difference between the sample and a blank.

Soil Cellulolytic Activity Assay

Cellulolytic activity was determined using modified method by (Vostrov and Petrova, 1961). Prior to the use, filter papers were dried at 105°C to the constant mass and cooled in the desiccator. 20 g of air-dried soils were weighed and transferred into labelled petri dish and the soils were slightly compacted. Thereafter, the weighed filter paper was placed on top of the compacted soil and 10 g of soil was weighed and placed on top of the filter paper. The content in the petri dish was compacted again and distilled water was added drop wise until saturation is achieved. The petri dish was then covered with a lid and incubated in the dark at 30°C for 24 hours. After incubation, filter paper was removed and carefully rinsed with distilled water and re-dried at 105°C to the constant mass. The amount cellulose is the difference between dry weight of filter paper, before and after incubation.

Catalase Activity Assay

Catalase activity was determined according to the protocol described by Kappen method (Frincu *et al*., 2015). A 3 g of moist soil was weighed and mixed with 10 mL of distilled water and 2 mL of 0.3 % H_2O_2. The slurry was then shaken for 20 minutes at 150 rpm. Thereafter, 10 mL of 4 M H_2SO_4 was added to stabilize H_2O_2 in the solution. Then, the solution was incubated at room temperature for 1 hour. Therefore, a solution was titrated against 0.05 M $KMnO_4$ until the end-point of the faint-pink coloured solution is attained.

Urease Activity Assay

Urease activity was estimated according to the procedure described by Kandeler and Gerber method (1988). The method is based on the determination of released ammonia after incubation of soil with urea solution for 2 hours at 37°C. Urease activity was determined using non-buffered method. 5 g of fresh moist soil was weighed and placed in a 100 mL Erlenmeyer, followed by the addition of 2.5 mL urea

solution. For blank, 2.5 mL distilled water was transferred into Erlenmeyer flask. The Erlenmeyer flask for both sample and blank were closed by a stopper and incubated for 2 h at 37°C. After the incubation, 2.5 mL urea solution was added to the control flask only. Thereafter, 50 mL of potassium chloride solution was then added to both samples and blank flasks, followed by shaking for 30 minutes at room temperature and then filtered through filter paper. Ammonium content in the filtrate was estimated using a UV/visible spectrophotometer at 690 nm.

Acid-Phosphatase Activity Assay

Acid phosphate activity was estimated according to the method described (Guan *et al*., 1987). This protocol is based on the determination of *p*-nitrophenol released after the incubation of the soil with *p*-nitrophenyl phosphate for 1 h at 37 °C. 1 g of fresh moist soil was mixed with 0.2 mL toluene and 4 mL of modified universal buffer (MUB) stock solution for the assay of acid phosphatase and then shaking for few minutes. After mixing the content, soil solution was incubated at 37°C for 1 hour. After incubation, 1 mL of 0.5 M $CaCl_2$ and 4 mL of 0.5 M NaOH were added to sample and blank. 1 mL of *p*-nitrophenyl phosphate solution was added to blank only. The samples were then swirled for few minutes to mix the content and filtered using filter paper. The *p*-nitrophenol was measured using UV/visible spectrophotometer at 410 nm.

3.3.2 Physico-Chemical properties

Organic phosphorus

Organic phosphorus was determined using the ignition method (Walker and Adams, 1958). A 1 g of air-dried soil sample was weighed and placed in a porcelain crucible and then a crucible was placed in a cool muffle furnace. The muffle furnace temperature was raised to 550°C over a period of 1 to 2 hours. After 2 hours, crucible was allowed to cool for 1 hour in the muffle furnace and then ignited soil was transferred to a 50 mL polypropylene centrifuge tubes.

A 1 g of air-dried soil was placed in a separate polypropylene centrifuge tube. 50 mL of 1 N H_2SO_4 will be added to both polypropylene centrifuge tubes with ignited and unignited soil and both samples were placed on the mechanical shaker for 16 h. Soil samples were centrifuged for 15 minutes at 3500 rpm.

A 1 N H_2SO_4 from polypropylene was pipetted into 50 mL volumetric flask followed by 5 drops of 0.25 % *p*-nitrophenol and neutralized with 5 N NaOH. The sample was diluted to 40 mL with distilled water. The 8 mL of phosphorus reagent was added and thereafter the content was mixed well. After 10 minutes, the absorbance was measured at 880 nm using 1-cm cuvette. The organic P = OP extracted from ignited sample – OP extracted from unignited sample.

3.3.3 Other soil properties

Soil pH was determined in water (1:2.5 soil: solution ratio) and cation exchange capacity using methods described by (Peech, 1965). Soil organic carbon was determined using Walkley and Black procedure (Nelson and Sommers, 1982). Soil samples for total nitrogen and Cation exchange capacity determination were determined using Kjeldahl (Bremner and Mulvaney, 1982) method. Particle size distribution was determined using hydrometer method described by (Bouyoucos, 1962).

3.3.4. Data analysis

Semi variograms were obtained from semi variances, γ (h), of each set of spatial observations calculated as follows.

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[\left(Z(Xi)-Z(Xi+h)^2\right]\right. \qquad [1]$$

Where:

γ (h) = Semi-variance of estimated experimental data,

N (h) = number of pairs of observations Z (x_i),

Z (x_i+h), separated by a vector h.

The nugget/sill ratio was used as criteria to classify the strength to the spatial dependence of soil properties. In general, nugget/sill ratio < 25% will indicate strong spatial dependency, between 25 and 75% moderate spatial dependency and >75% weak spatial dependency (Cambardella *et al*., 1994). Analytical results and their corresponding geographical coordinates were used for soil fertility and levels map production. The spatial field variability was accomplished using surfer 8.0 software, while surface interpolation of vector data using the ordinary kriging method in ArcMap of ArcGIS 10.5 (Warrick *et al*., 1986). Kriging is used to estimate and map soil in un-sampled areas. Kriging was computed using equation [1].

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

According to the results, mean values for soil pH varied between 6.20 and 8.89 for both sites (Table 1). This reveals that the soil at University of Venda Experimental Farm is slightly acidic, whereas the soils on Roodeplaat Experimental Farm are strongly alkaline. Approximately 58% of South African soils contain <0.5% organic C, 38% contain 0.5 to 2% organic C, and 4% contain >2% organic C (Du Preez *et al*., 2011). Thus, the organic carbon for both sites fall within the range. However, the highest organic carbon were noted at University of Venda Experimental Farm (1.25%) as compared to Roodeplaat Experimental Farm (0.91%).

Table 1. Soil Characterisation for University of Venda and Roodeplaat Experimental Farms

Soil properties	Min	Max	Mean	S.D	CV, %
Site 1					
Sand, %	36	58	52.33	6.14	11.73
Silt, %	21	40	35.92	5.57	15.51
Clay, %	2	27	11.75	8.59	73.11
Soil pH	5.77	6.64	6.20	0.21	3.38
OC, %	0.61	2.43	1.25	0.56	44.8
CEC, cmol/kg	0.08	0.44	0.25	0.11	44
Site 2					
Sand, %	34	42	37.67	2.81	7.46
Silt, %	32	42	39	4.13	7.46
Clay, %	20	28	23.33	1.97	8.44
Soil pH	6.4	7.26	8.89	8.89	2.14
OC, %	0.65	1.11	0.91	0.13	14.29
CEC, cmol/kg	0.08	0.42	0.20	0.10	50

Min, Minimum; Max, Maximum; S.D, Standard Deviation; CV, Coefficient of Variation
CEC: Exchangeable Cation Capacity

Summary of descriptive statistics for measured soil fertility indicators in 0-200mm depth for University of Venda and Roodeplaat Experimental Farms is presented in (Table 2). The parameters were classified into low (< 20%), moderate (20-50%) and high (> 50%) variable classes as proposed by Aweto (1982) cited in Amuyou *et al*., 2013. Results showed that the variation coefficient of Cellulolytic (0.40%), Catalase (1.66%), Acid phosphatase (6.57%), Total nitrogen (10%) belonged to low variation intensity at University of Venda Experimental Farm. On the other hand, the variation coefficient of soil respiration (39.56%), Urease (30.80%), Organic phosphorus (44%) and Organic carbon (44.8%), belonged to moderate variation intensity (Table 2). None of the measured parameters at University of Venda Experimental Farm exhibited strong variation intensity. The highest variation coefficient was noted in OC (44.8 %) and the lowest variation were noted in Cellulolytic (0.40 1.66%). The results at Roodeplaat Experimental Farm reveals that only Catalase (1.16e+01%) and OC (14.29%) belonged to low variation intensity. And only Urease (32.11%) belonged to moderate variation intensity whereas Acid phosphatase (4.14e+16%), soil respiration (77.27%), organic phosphorus (72.22%) and total nitrogen (51%) belonged to high variation intensity for Roodeplaat Experimental Farm (Table 2). Furthermore, the measured parameters with the highest and lowest coefficient of variation were soil respiration (77.27%) and Catalase (1.16e+01%), respectively. The variation in soil properties could be attributed due variation in prevailing climatic conditions, management practices, soil types and pedogenic processes. Bhunia *et al*., 2018 has reported soil pH (5.30%) and sand (0.2%) with low coefficient of variation and OC (22.39%) with moderate coefficient of variation Lateritic and Alluvial soils.

Table 2. Descriptive Statistics of Soil Fertility Indicators.

Soil properties	Min	Max	Mean	S.D	CV%
Site 1					
R_S, g $CO_2m^{-2}d^{-1}$	0.76	4.3	2.3	0.91	39.56
Cel, %	0.01	0.03	0.02	0.01	0,40
Cat, ml0.02mkmno4/g/20min	1.20e-03	1.26e-03	1.23e-03	2.04e+11	1.66e+16
UAc, µg-nh4-n g^{-1} dwt2h^{-1}	34.57	108.40	70.94	21.84	30.80
Pac, ug/dwth^{-1}	1.00e+04	1.32e+04	1.22e+16	8.02e+15	6.57e+01
Po, %	0.08	0.44	0.25	0.11	44
OC, %	0.61	2.43	1.25	0.56	44.8
TN, %	0.07	0.12	0.10	0.01	10
Site 2					
R_S, g $CO_2m^{-2}d^{-1}$	0.14	2.34	0.88	0.68	77.27
Cel, %	0.02	0.09	0.04	0.02	50
Cat ml0.02mkmno4/g/20min	1.00e-04	3.00e-04	1.92e-04	7.93e+10	1.16e+01
Ur, µg-nh4-n g^{-1} dwt2h^{-1}	15.22	41.85	29.80	9.57	32.11
Ap, ug/dwth^{-1}	8.61e+07	1.34e+08	1.18e+16	1.36e+15	4.14e+16
Po, %	0.01	0.43	0.18	0.13	72.22
OC, %	0.65	1.11	0.91	0.13	14.29
TN, %	0.10	0.09	0.08	0.004	51

R_S: Soil respiration, Cel: Cellulolytic, Cat; Catalase, UAc: Urease, Pac; Acid phosphatase, Po: Organic phosphorus, OC: Organic carbon, TN: Total Nitrogen

Table 3. Semivariograms Analysis of Soil Fertility Indicators.

Soil properties	Model	Range (m)	Nugget	Sill	Spatial ratio	Spatial class
Site 1						
R_s, g $CO_2m^{-2}d^{-1}$	Exponential	1.41e-03	0	1.42	0	S
Cel, %	Exponential	5.01e-04	5,26e-06	0	17,00	S
Cat, ml0.02mkmno4/g/20min	Exponential	1.32e-03	3.16e-10	0	47,40	M
UAc, µg-nh4-n g^{-1} $dwt2h^{-1}$	Exponential	1.41e-03	476.77	476.77	100	W
Pac, $ug/dwth^{-1}$	Gaussian	1.41e-03	9.03e-03	0.01	69.20	M
Po, %	Exponential	1.41e-03	9.03e-03	0.01	69.20	M
OC, %	Gaussian	1.23e-03	1.15e-01	0.68	16.90	S
TN, %	Exponential	1.41e-03	1.82e-04	0	100	W
Site 2						
R_s, g $CO_2m^{-2}d^{-1}$	Exponential	0.02	0	0.75	0	S
Cel, %	Gaussian	0.02	4,23e-04	4,23e-04	100	W
Cat, ml0.02mkmno4/g/20min	Exponential	0.02	3.55e-09	8.27e-09	4.29e+01	S
UAc, µg-nh4-n g^{-1} $dwt2h^{-1}$	Exponential	0.01	0	1.08e+02	0	S
Pac, $ug/dwth^{-1}$	Exponential	0.02	1.00e+06	2.47e+06	40.66	M
Po, %	Exponential	0.01	1.26e-03	1.93e-02	6.55	S
OC, %	Exponential	0.01	0	0.02	0	S
TN, %	Exponential	0.02	6.72e-06	2.75e-05	24.39	S

S, Strong, M, Moderate, W, Weak spatial dependence

4.1 Spatial variability and distribution of soil fertility indicators

4.1.1 Biological indicators

4.1.1.1 Soil respiration

Semi variograms were calculated and the best models that describes the spatial structure was identified (Table 3). Exponential models were fitted for soil respiration (R_S) at both sites (Figures 3). The nugget to sill ratio for soil respiration was <25% at University of Venda Experimental Farm, thus exhibited strong spatial dependence. On the other hand, soil respiration at Roodeplaat Experimental Farm had >75% nugget to sill ratio, thus exhibiting weak spatial dependence (Table 3). The spatial dependence of soil respiration at University of Venda and Roodeplaat Experimental Farm with distance is thus limited to 1.41e-03 and 0.02m range, beyond which there is no spatial dependence, respectively. Kriged maps for soil respiration at both sites (Figure 4). According to the observations, University of Venda Experimental Farm had greatest soil respiration distribution as compared to Roodeplaat Experimental Farm. Hence, highest and lowest soil respiration values were observed on the South-North and West-East of the study site on University of Venda Experimental Farm, while for Roodeplaat Experimental Farm the highest and lowest were on the North-East and South-West of the study site, respectively.

Exponential models were fitted for soil respiration at both sites. La Scala *et al*., 2000 reported that spherical model fits well with experimental semivariogram for soil respiration. However, Ohashi and Gyokusen (2007) observed that spatial variability of soil respiration in a forest was demonstrated by different kinds of models (exponential, linear and spherical) depending on the seasons. The spatial dependency of the data was assessed from the ratio of nugget and sill (Table 3). Cambardella *et al*. (1994) defined this ratio of <25% for strong, 25% to 75% for moderate, and >75% as weak spatial dependence. According to this classification, soil respiration showed a strong spatial dependence at University of Venda Experimental Farm and exhibited weak degree of spatial dependence on Roodeplaat

Experimental Farm. Spatial dependence soil properties may be attributed to either extrinsic, intrinsic or both factors (Behera *et al*., 2011). Based on the results of the present study we may conclude that weak spatial dependence of soil respiration could be usually attributed to extrinsic factors such fertilisations, tillage and crop management practices. Moreover, the findings are consistent with the researches of Wang *et al*., 2009 and Vasu *et al*., 2017. Strong spatial dependence of soil respiration was noted on University of Venda Experimental Farm and hence could be due to intrinsic factors like parent material, soil types, climate and topography. This site only used for livestock grazing. Hence, prior sampling it have been ploughed. Therefore, the ploughing could be also be reason for this strong spatial dependence. Because ploughing promotes uniformity in the field.

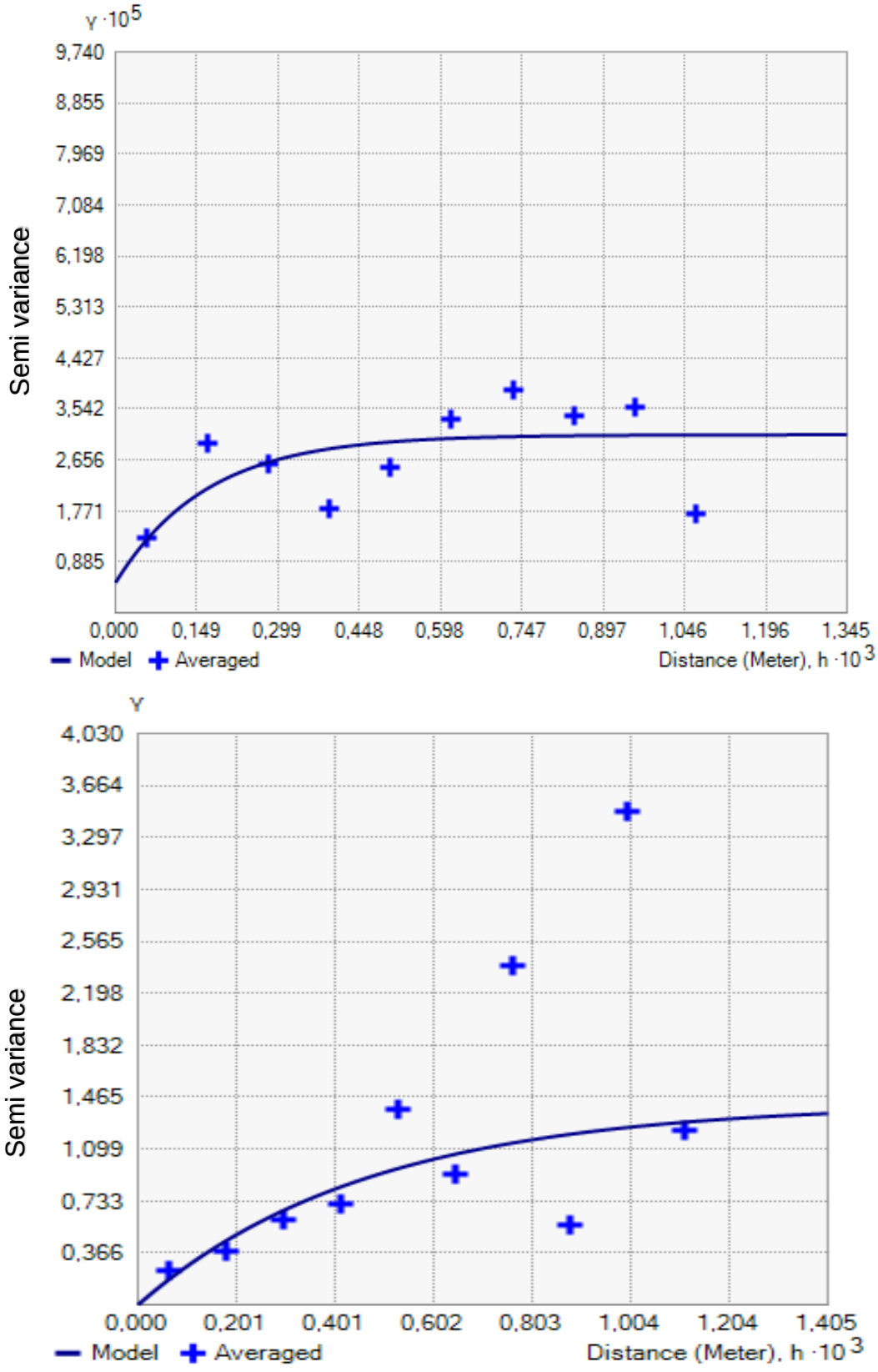


Figure 3. Soil respiration variograms for University of Venda (Top) and Roodeplaat Experimental Farms (Bottom)

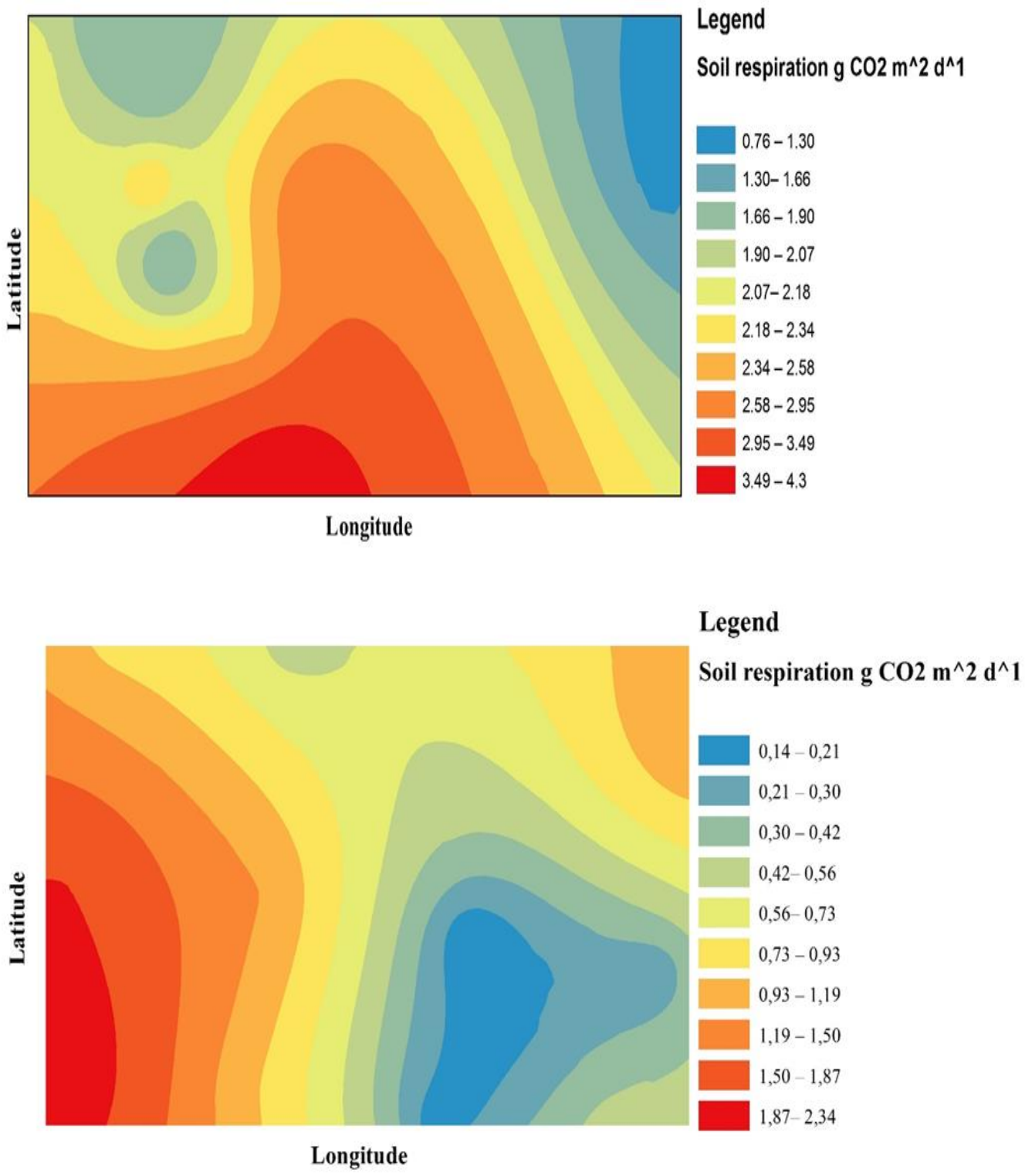


Figure 4. Kriged maps for soil respiration for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.1.2 Soil cellulolytic

The exponential and Gaussian model was the best fit for cellulases at University of Venda experimental and Roodeplaat Experimental Farms, respectively (Figure 5). The nugget to sill ratio at University of Venda and Roodeplaat Experimental Farms were 17 and 100%, respectively. Thus exhibiting strong spatial dependence at University Venda experimental Farm, whereas the weak spatial dependence on Roodeplaat Experimental Farm. Kriged maps for cellulases distribution at both sites (Figure 6). Cellulases were more distributed on University of Venda Experimental Farm more than at Roodeplaat Experimental Farm. Hence, patchy distribution of cellulases with higher values occurring on the North-South and in the centre and the lower at the East-West of the study site (Figure 6: top map).

The activities of cellulases in agricultural soils are affected by several factors these include temperature, soil pH, water and oxygen contents, the chemical structure of organic matter and its location in the soil profile horizon, quality of organic matter/plant debris and soil mineral element and the trace elements from fungicides (Klein, 1989; Sinsabaugh and Linkins, 1989; Arinze and Yubedee 2000). The cellulases enzyme activity was spatial dependent and distributed at University of Venda Experimental Farm more than that of Roodeplaat Experimental Farm. This heterogeneity could be influenced by management practices such fertilisation, tillage system, crop variety, and residue quality. Similarly, Piotrowska *et al*., 2011 reported weak spatial dependent for cellulases enzyme activities in an arable land and suggested that this could controlled by application of fertilisers and tillage systems. In the present study cellulases exhibited weak spatial dependence in the field which has been used for agronomic practices. Thu, this suggest that agronomic practices such as tillage systems, crop variety and fertiliser applications reduces the spatial dependence of cellulases to the core. Contrarily, strong spatial dependence reported in virgin soils at University of Venda Experimental Farm, which has been only utilised for livestock grazing. Therefore, in conclusion strong spatial dependence could be due to intrinsic factors. A considerable relationship between cellulases and organic carbon distributions within the field at University Venda Experimental Farm (Figure 6 and 16: top maps) were noted. The highest and lowest distribution for both cellulases

and organic carbon were noted on the North-South and West-East of the study site, respectively. Therefore, this confirm that cellulases heterogeneity could controlled by present of soil organic matter and its degree of degradability.

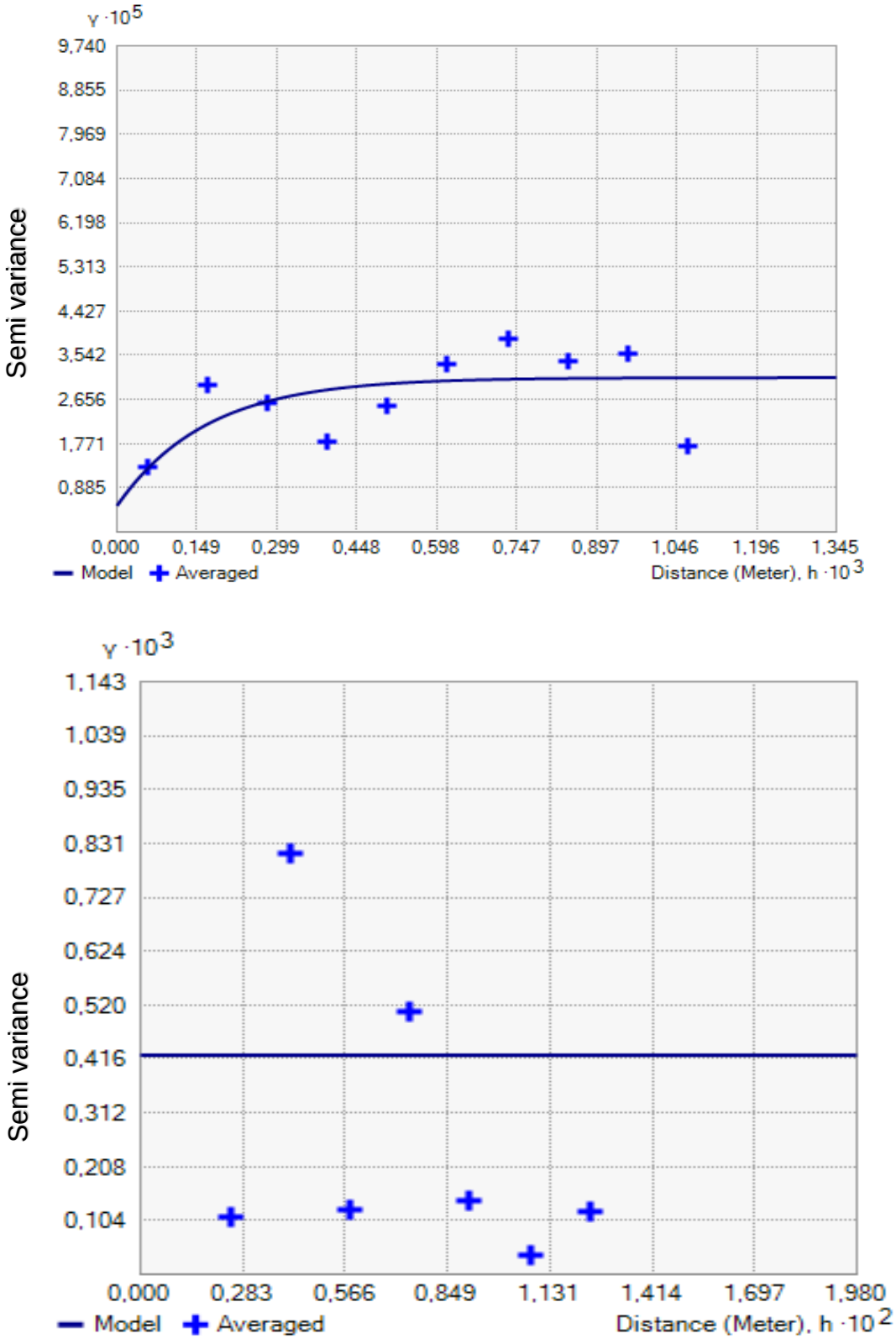


Figure 5. Cellulolytic variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

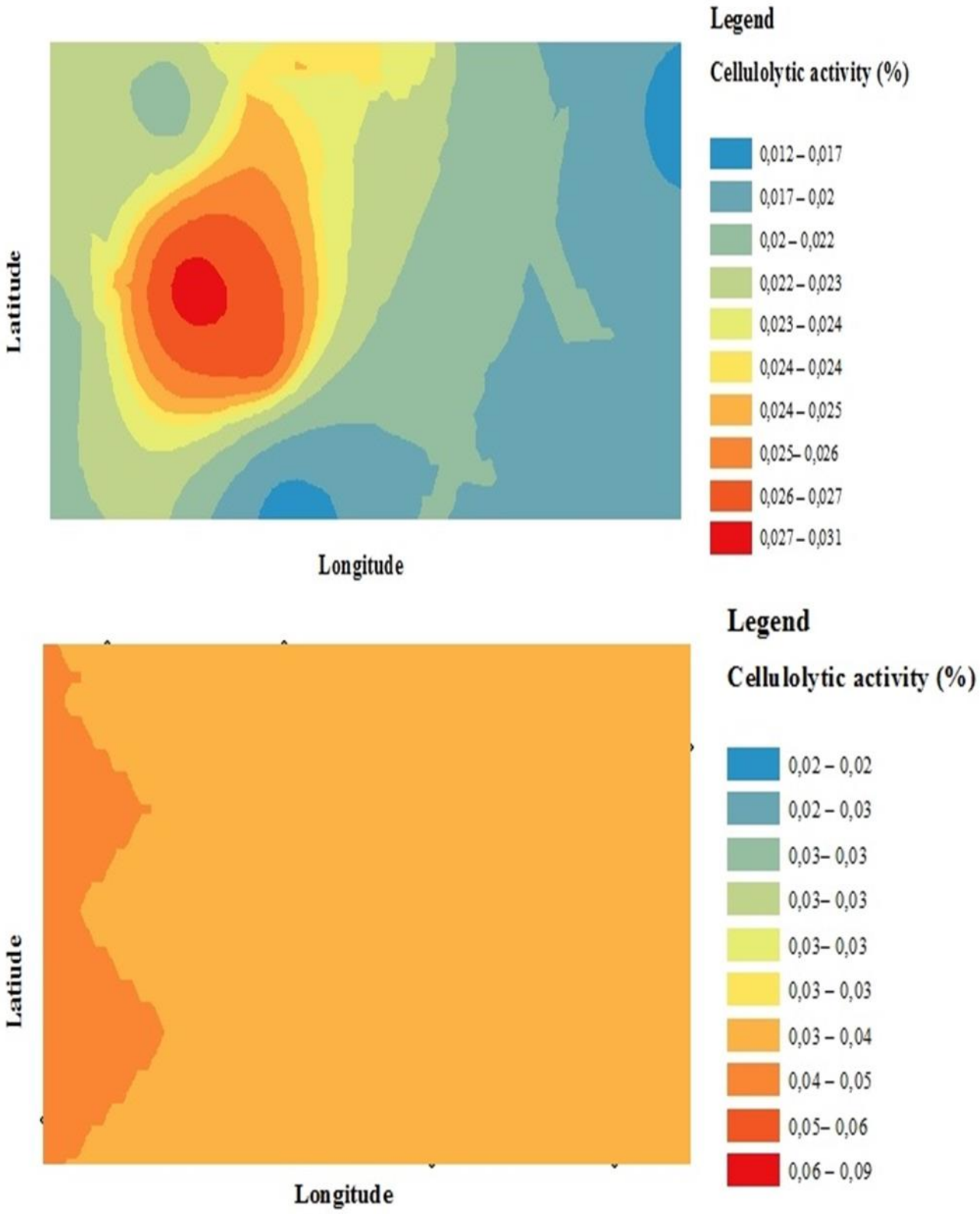


Figure 6. Kriged maps for Cellulolytic for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.1.3 Catalase

The exponential model provided the best fit for catalase at both sites (Figure 7). Nugget to sill ratios of urease activities at University of Venda Experimental Farm was 47. 40%, thus exhibiting moderate spatial dependence (Table 3). Nugget to sill ratios of urease activities at Roodeplaat Experimental Farm was 4.29e+01%, thus exhibited strong spatial dependence. According on the results, the bottom map had highest catalase distribution as compared to top map (Figure 8). The highest catalase distribution was observed on the North-East and the lowest on the South-West part of the study site (Figure 8: Bottom map).

The catalase heterogeneity and distribution were noted on Roodeplaat Experimental Farm as compared to University of Venda experimental Farm. When the literature were examined it seems that there is a paucity of information on the spatial and distribution of catalase in the soil worldwide. However, catalase heterogeneity could be controlled by oxygen variability across and within the field. Soil redox status is an important microbial driver in surface soils Hall and Silver, 2013. Furthermore, catalase split hydrogen peroxide into molecular oxygen and water and thus prevent cells from damage by reactive oxygen species (Yao *et al*. 2006). However, oxygen in this study was not measured.

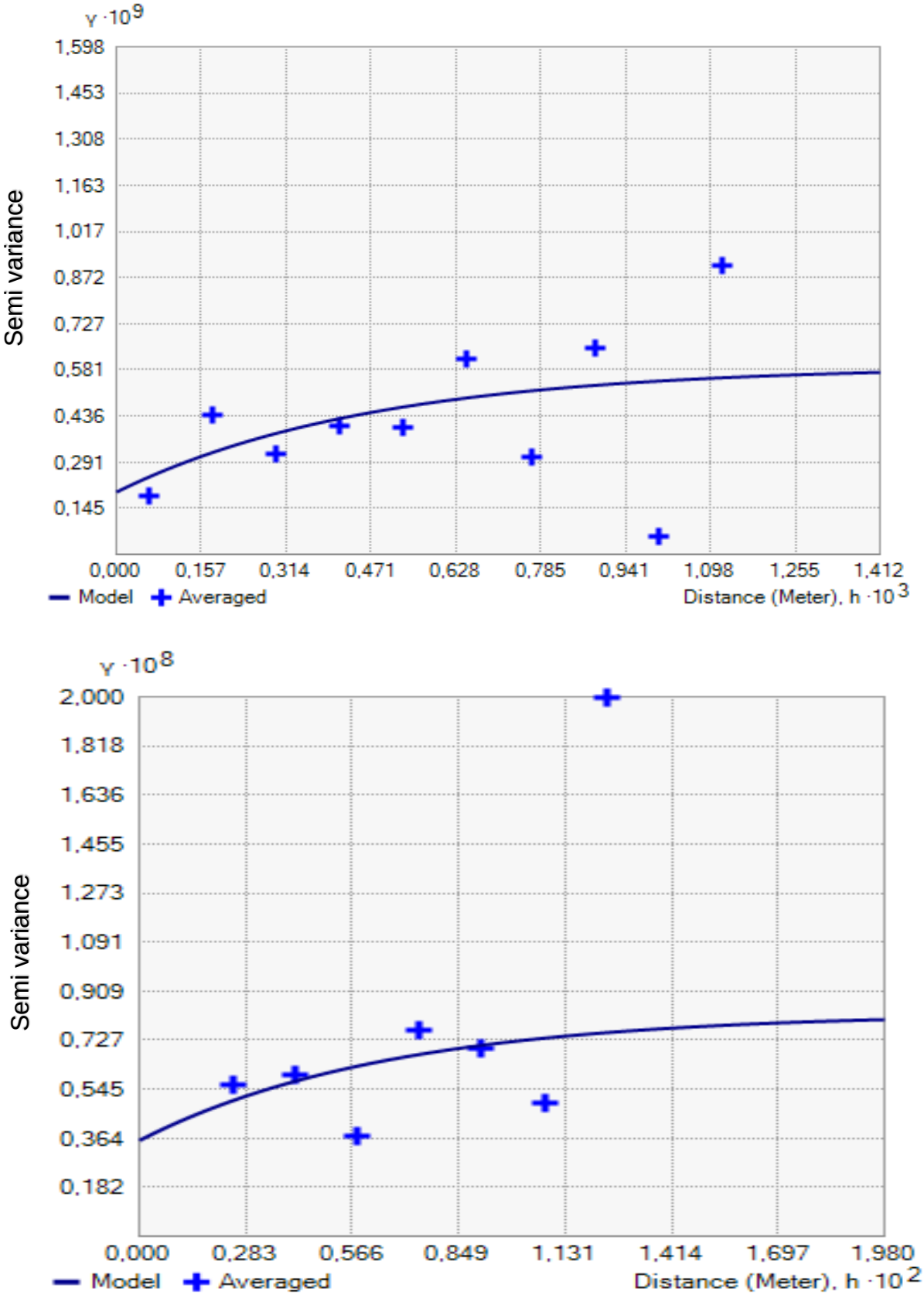


Figure 7. Catalase variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

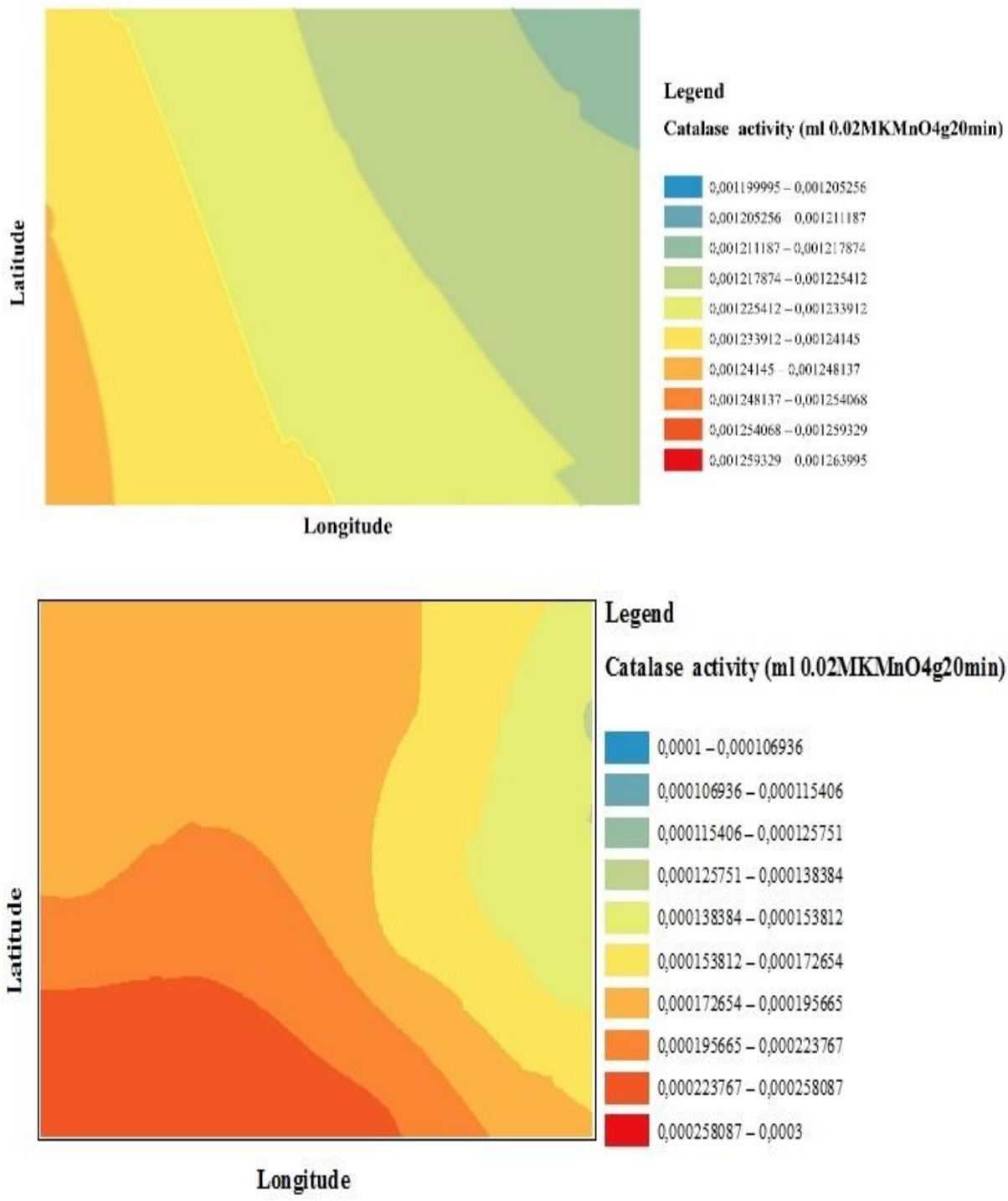


Figure 8. Kriged maps for Catalase for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.1.4 Urease activity

The Gaussian and exponential model provided the best fit for catalase at University of Venda experimental and Roodeplaat Experimental Farms, respectively (Figure 9). Urease exhibited weak (100%) and strong spatial dependence (0%) at University of Venda and Roodeplaat Experimental Farms, respectively (Table 3). The range distance for University Venda experimental Farm was 1.32e-03 and 0.01m for Roodeplaat Experimental Farm (Table 3). The ureases were more distributed at Roodeplaat Experimental Farm (Figure 10: Bottom map). Hence, urease activity was highly distributed on the North-East and least distributed on the South-West to the centre of the study site.

The urease heterogeneity and distribution at Roodeplaat Experimental Farm could attributed to the previous agronomic practices, as stated in the sites descriptions. Furthermore, during the last decades, chemical fertilizers have been applied to the field at this site (Roodeplaat Experimental Farm. Urease and total nitrogen were spatial dependent at Roodeplaat Experimental Farm more than at University of Venda experimental Farm. Similarly Tan *et al*., 2014 observed related trends for total nitrogen and urease distribution on the same aspect of the field. Urease heterogeneity and distribution could be due to over/under application of nitrogen containing fertilisers. For instance, uniform application of fertilizers often results in over/under application in various parts of the field due to in-field variability when spatial variability of soil is ignored (Khosla *et al*., 2002). Urease catalyses the hydrolysis of urea into ammonia and carbon dioxide (Mukumbareza *et al*., 2015). Urease activity is directly related to type of vegetation and quality of incorporated organic materials, soil organic matter and microbiological activities in the soil (Alef and Nannipieri 1995). Thus, urease heterogeneity could be also due to nature and quality of incorporated crop residues. D£ugosz *et al*., 2013 observed moderate spatial dependent for urease in an arable lands for both Phacozem and Luvisol. These findings confirmed that the spatial variability of soil enzymes varied in different ecosystem.

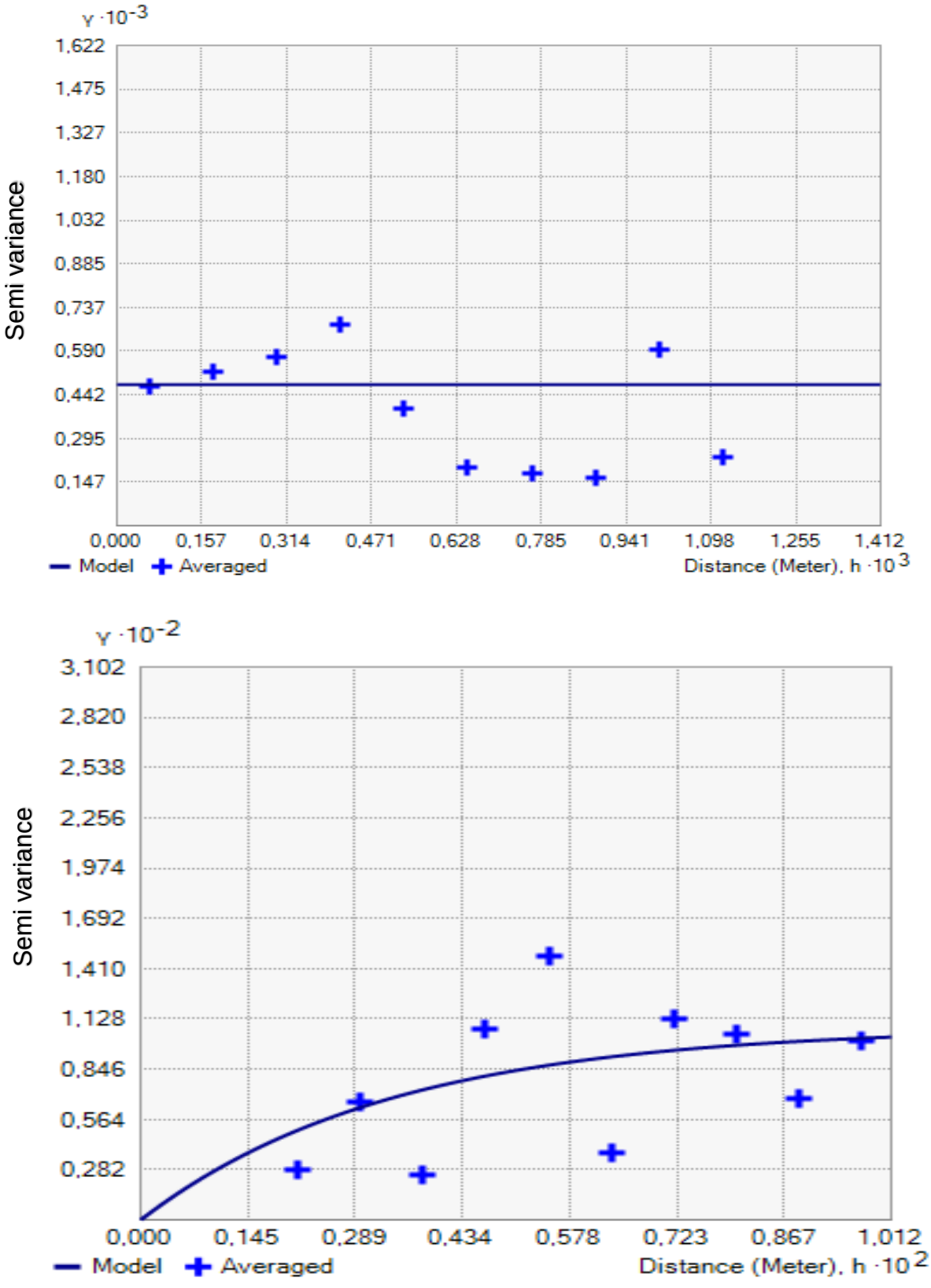


Figure 9. Urease variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

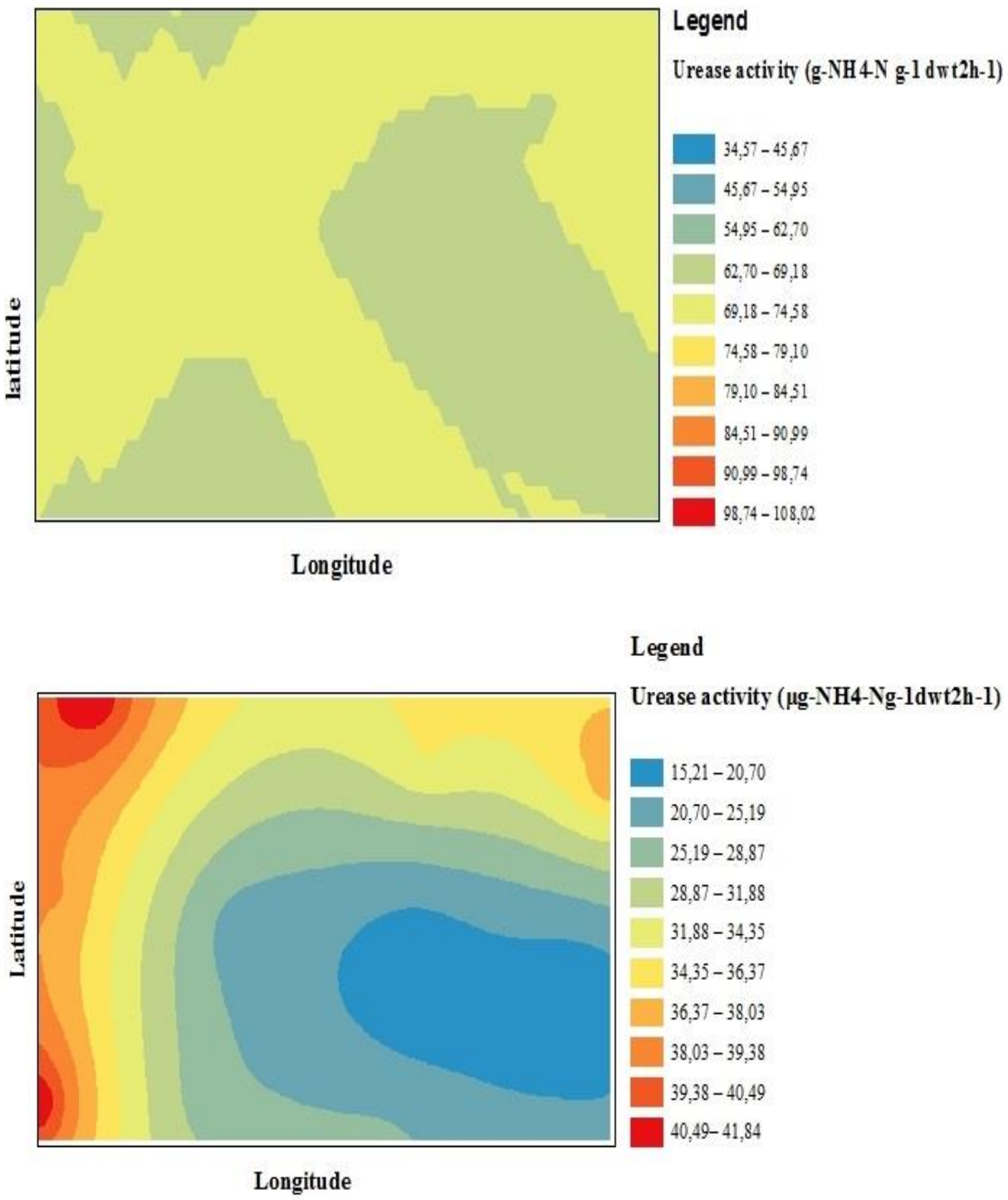


Figure 10. Kriged maps for Urease University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.1.5 Acid-Phosphatase

The Gaussian model provided the best fit for acid phosphatase at University of Venda Experimental Farm (Figure 11). Exponential model was the best fit at Roodeplaat Experimental Farm. The nugget to sill ratio is a good indicator whether a given soil variable is strongly spatially correlated (<25), moderately spatially correlated (25-75) or weakly spatially correlated (>75). Nugget to sill ratio for acid phosphatase for University Venda Experimental Farm and Roodeplaat Experimental Farm were 69.20 and 40.66%, respectively (Table 3). Acid phosphatase were moderately spatially dependent at both sites. Hence, acid phosphatase were slightly distributed in both sites (Figure 12).

Accordingly, acid phosphatase were not only moderately spatially correlated, but also the spatial correlation was apparent at the shortest ranges. The highest range were noted at Roodeplaat Experimental Farm (0.2 m) (Table 3). Contrarily concerning rang, acid phosphatase showed strong spatial correlation in the range of ~4 and 5 m for both sub and top soils, respectively (Negassa *et al*., 2019). Acid phosphatase in April exhibited strong spatial dependence, whereas in August moderate spatial dependence and spherical models were best fitted (Piotrowska-Długosz *et al*., 2016). Contrarily, in this study Gaussian and exponential models were the best fits for acid phosphatase, thus exhibiting moderate spatial dependence. Spatial dependence and distribution of acid phosphatase is a function of prevailing climatic conditions, season, soil types, topographic position and historical land use. The activities of the acid phosphatase enzymes are favored in aerobic soil conditions (Romanowicz *et al*., 2015). The rate of synthesis, release and stability of phosphatase depends on soil pH, and soil organic matter (Baldrian, 2014). Spatial dependence of acid phosphatase could be due to variation in soil pH and soil organic matter within the fields.

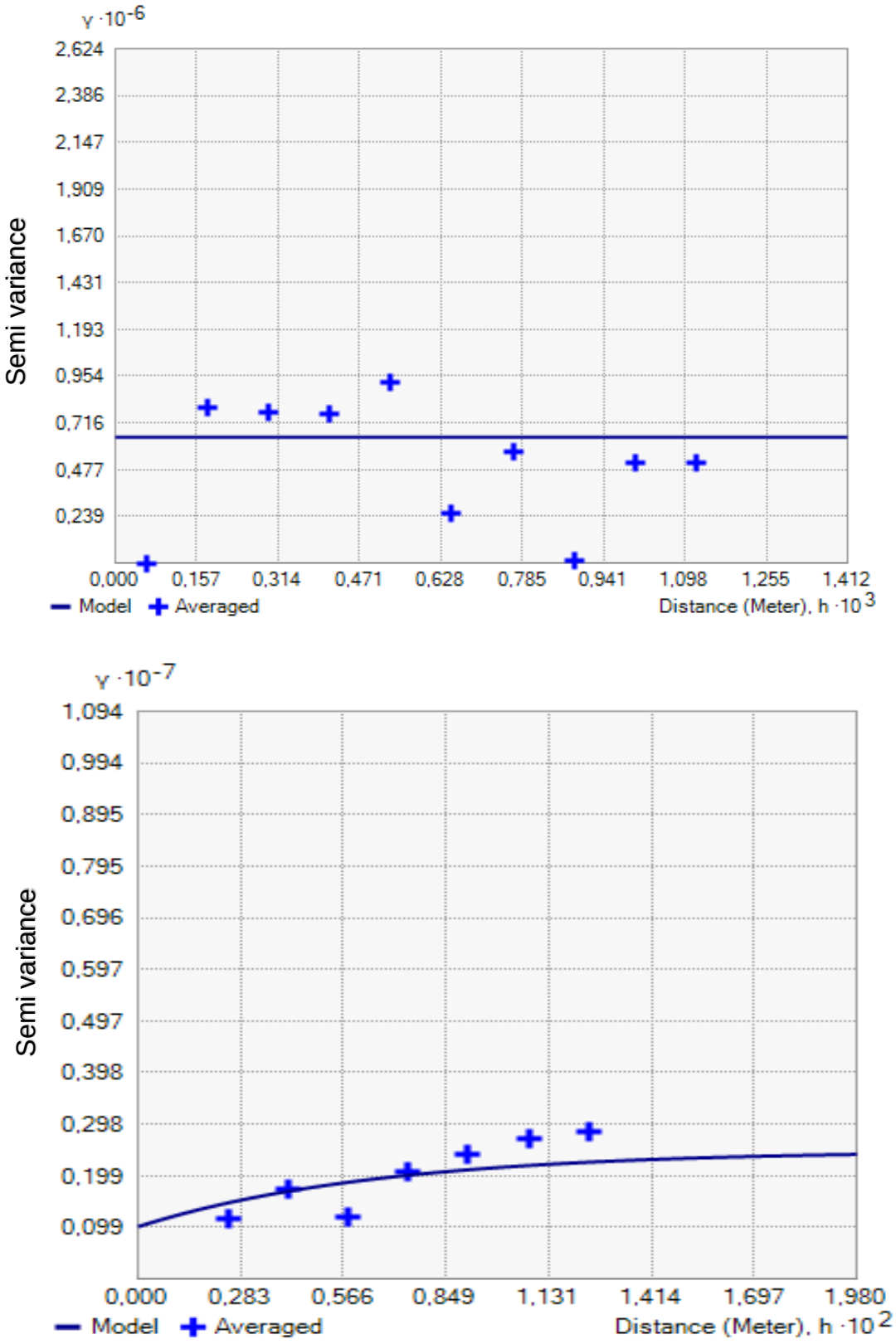


Figure 11. Acid phosphatase variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

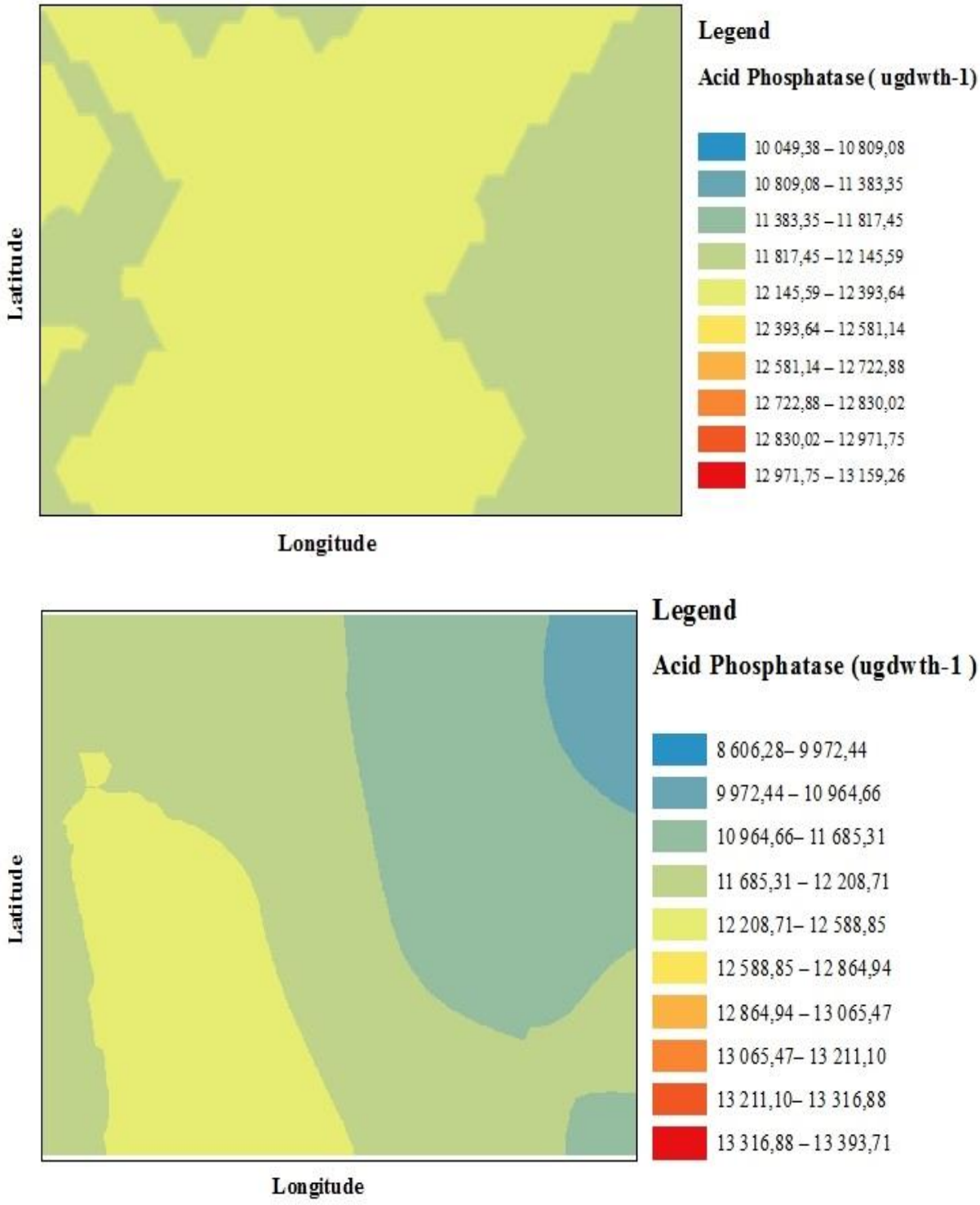


Figure 12. Kriged maps for Acid phosphatase for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.2 Chemical indicators

4.1.2.1 Organic phosphorus

The exponential model provided the best fit for organic phosphorus at both sites (Figure 13). This suggest that there is positive increase in spatial autocorrelation of organic phosphorus at both sites. The semi variograms for organic phosphorus at University of Venda Experimental Farm were between 25 and 75%, thus exhibiting moderate spatial dependence. Strong spatial dependence was noted on Roodeplaat Experimental Farm. Kriged maps for organic phosphorus distribution at both sites (Figure 14). The greater organic phosphorus distribution was observed on the North-East and lower on the South-West of the study site (Figure 16: Bottom map), respectively.

Phosphorus exists in soil in either inorganic or organic forms. Organic phosphorus can be a potential source of P for plants and microorganisms only after hydrolysis (Wang *et al*. 2011). Acid and alkaline phosphatases significantly contribute to the release of phosphorus in the soils and nutrient cycling, and therefore they are enzymes of great agronomic significance (Hui *et al*. 2013). The activities of soil alkaline and acid phosphatase are closely related to soil pH. Spatial dependence of organic phosphorus could due to factors affecting soil pH and phosphatase activities in the soil.

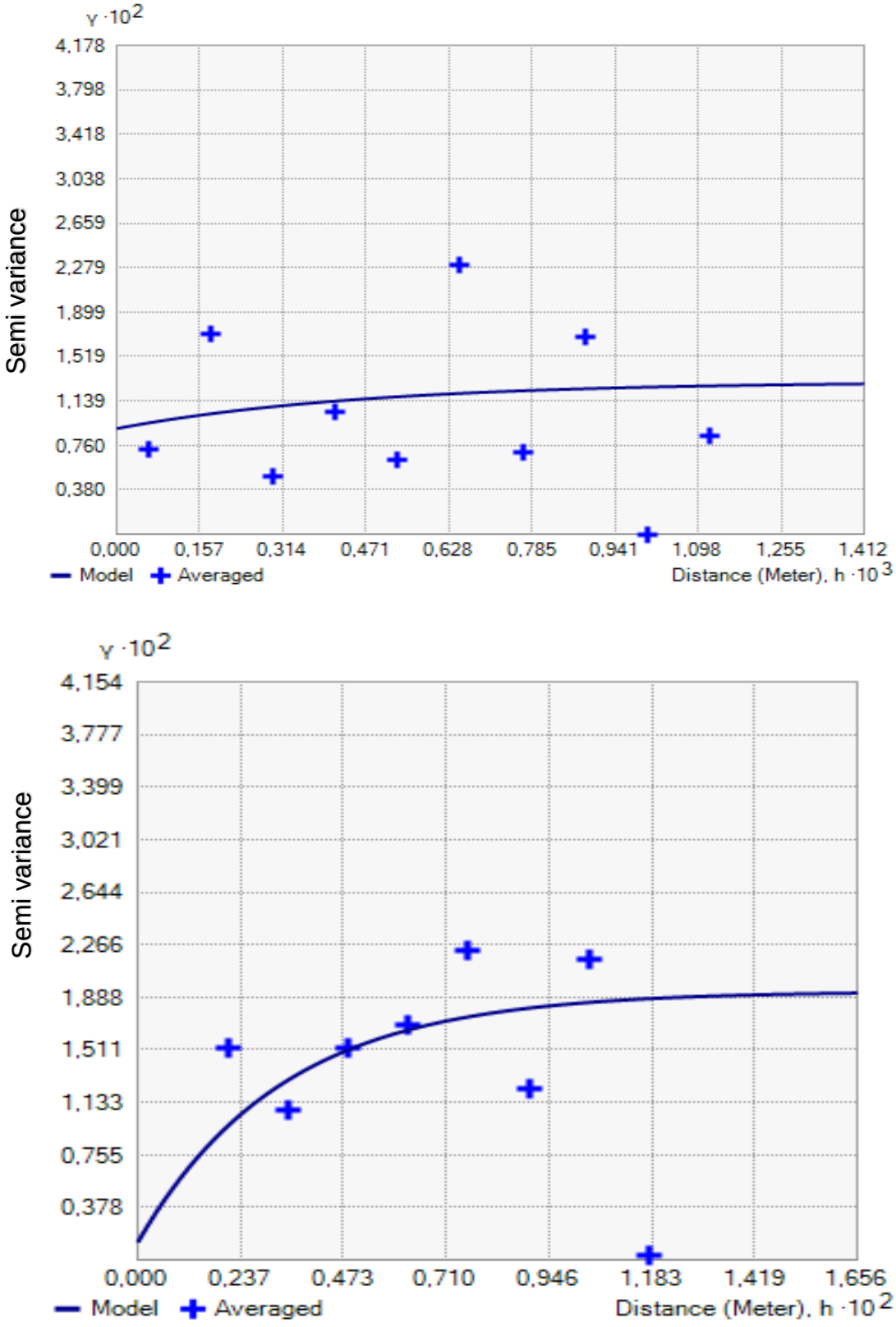


Figure 13 . Organic phosphorus variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

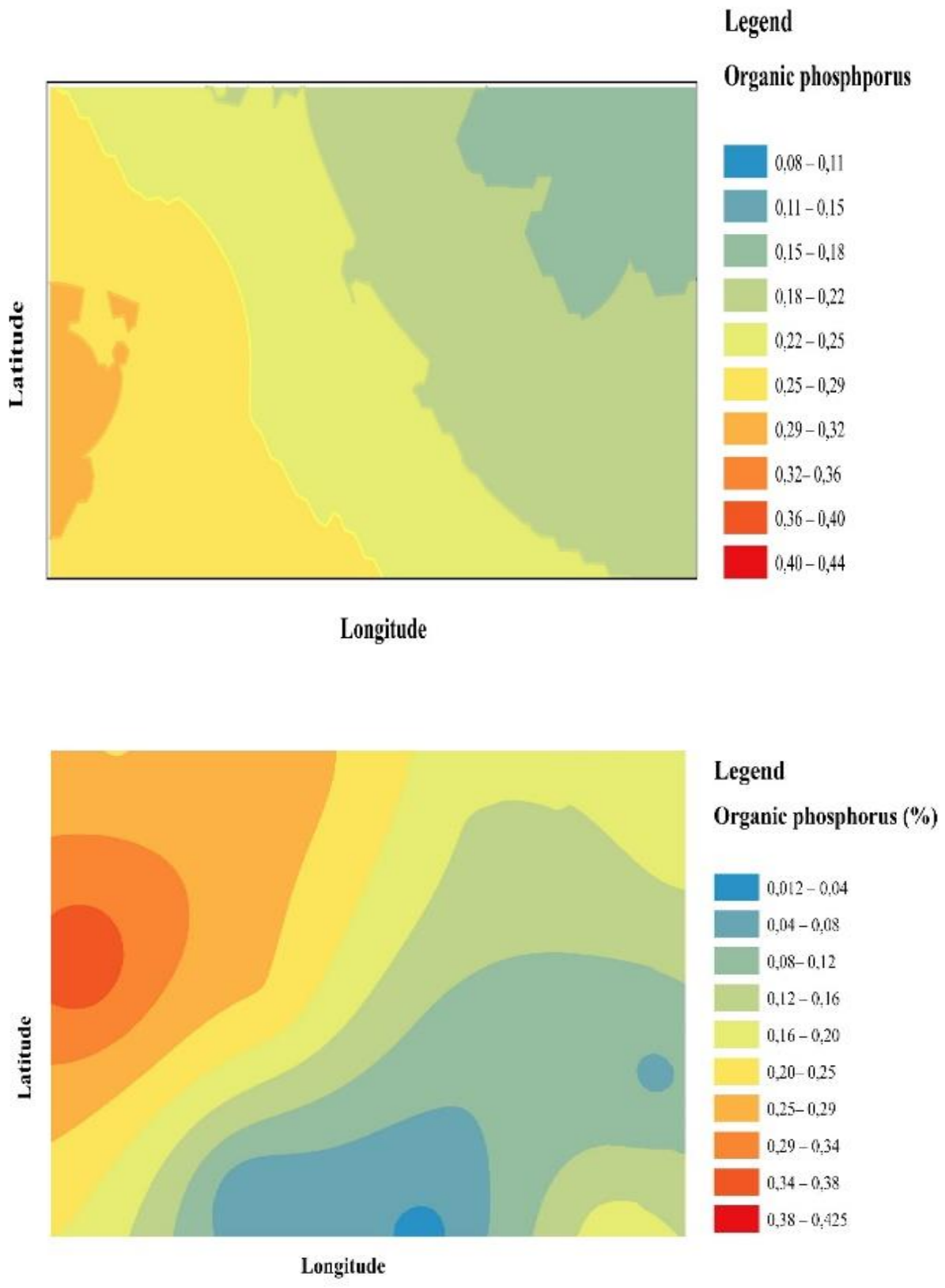


Figure 14. Kriged maps for Organic Phosphorus University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.2.2 Organic carbon

Organic carbon at University Venda Experimental Farm fitted well by a Gaussian model having a nugget/sill ratio of 16.90% and range of 1.23e-03 m (Figure 15). The exponential model was the best fit for organic carbon at Roodeplaat Experimental Farm with nugget/sill ratio of 0% and range of 0.01 m. Hence, organic carbon at both sites were strongly spatially dependent. Kriged maps for organic carbon showed that the highest and lowest organic carbon distribution were noted on the North-South and West-East on Venda experimental Farm and on the North-North and East-West for Roodeplaat Experimental Farm (Figure 16).

Soil spatial variability can develop from uneven litter decomposition, vegetation composition, soil moisture content, topographic position, and historical land use, and soil management practice (Baldrian, 2014). In the present study, organic carbon at both sites were strongly spatially auto-correlated. Similarly, strong spatial dependence for organic carbon in different ecosystems were reported by Liu *et al*., (2014); Tagore *et al*., (2014). Roodeplaat Experimental Farm have been used for sweet potatoes cultivation. The fertilisers and herbicides used were NPK and Grazon, respectively. On the other hand, University Venda Experimental Farm have been used for livestock grazing. Thus, these two sites have been utilised for different purposes, but organic carbon exhibited strong spatial dependence. This suggest that the spatial and distribution of organic carbon within the fields could be attributed due to intrinsic, extrinsic or the effects of both factors. Wang *et al*., (2009) reported that extrinsic factors such as fertilization and cultivation practices causes spatial variability of soil properties. Therefore, the spatial variability is somewhat function of prevailing environmental factors, soil types, management practices and soil forming processes.

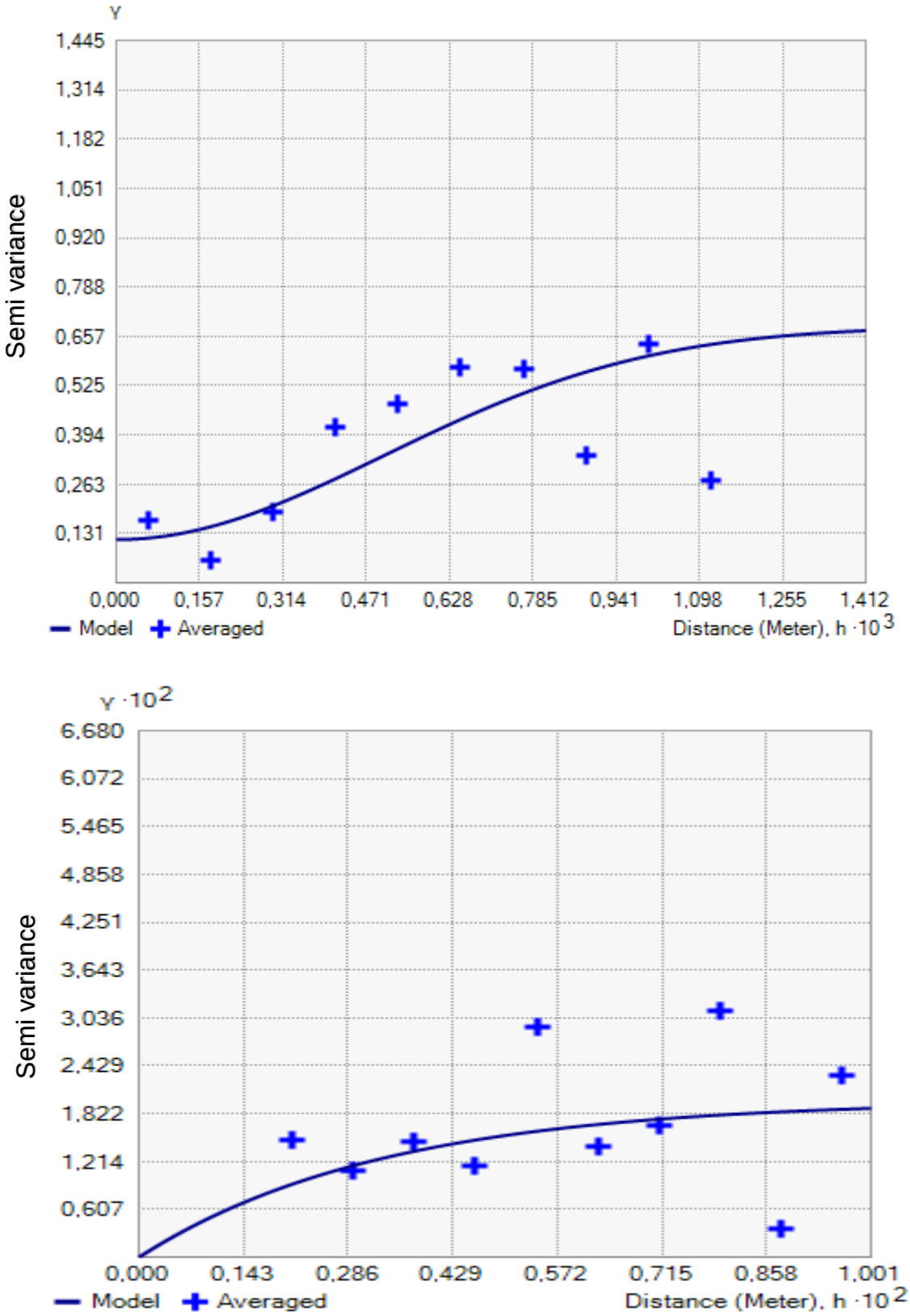


Figure 15. Organic carbon variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

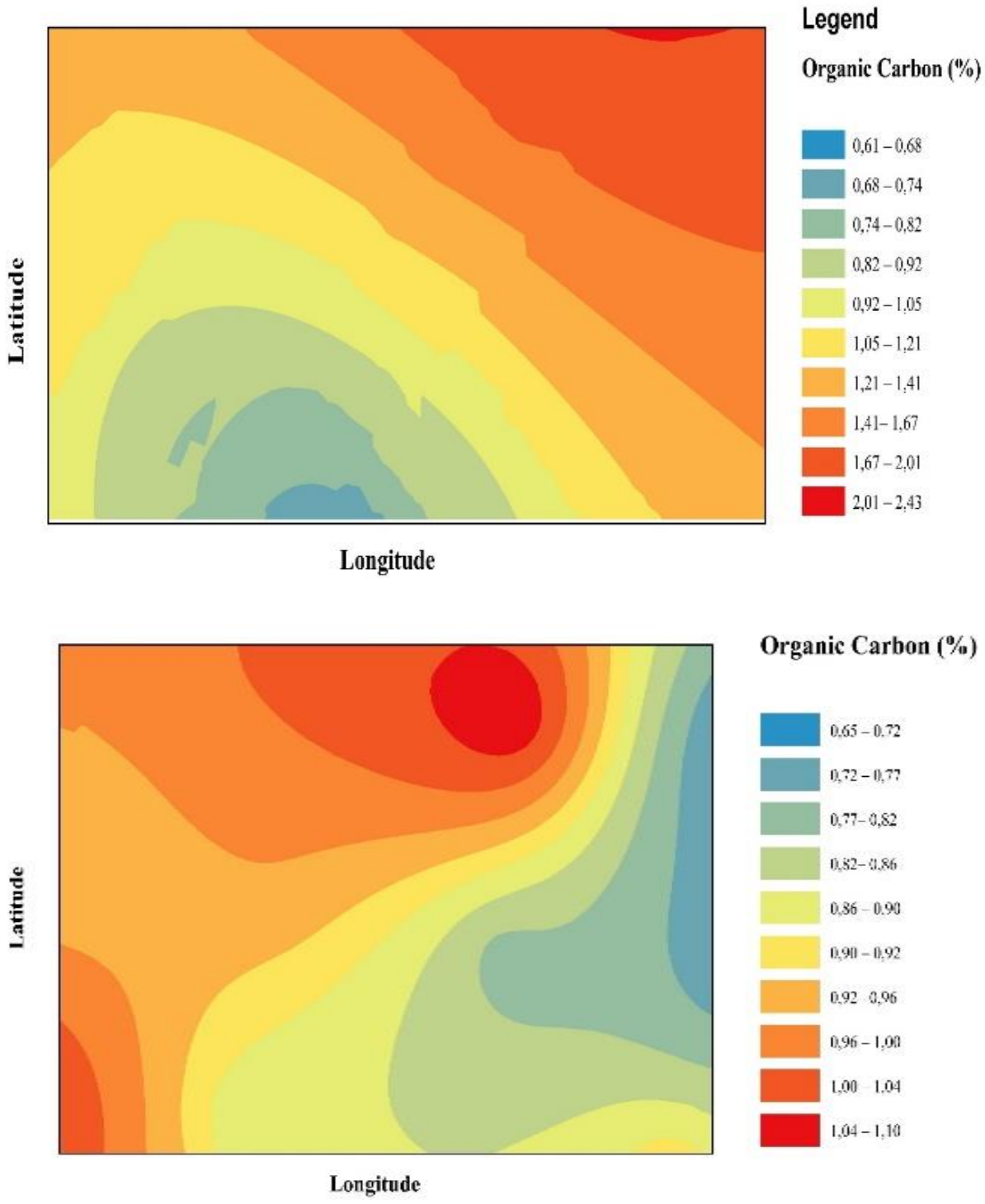
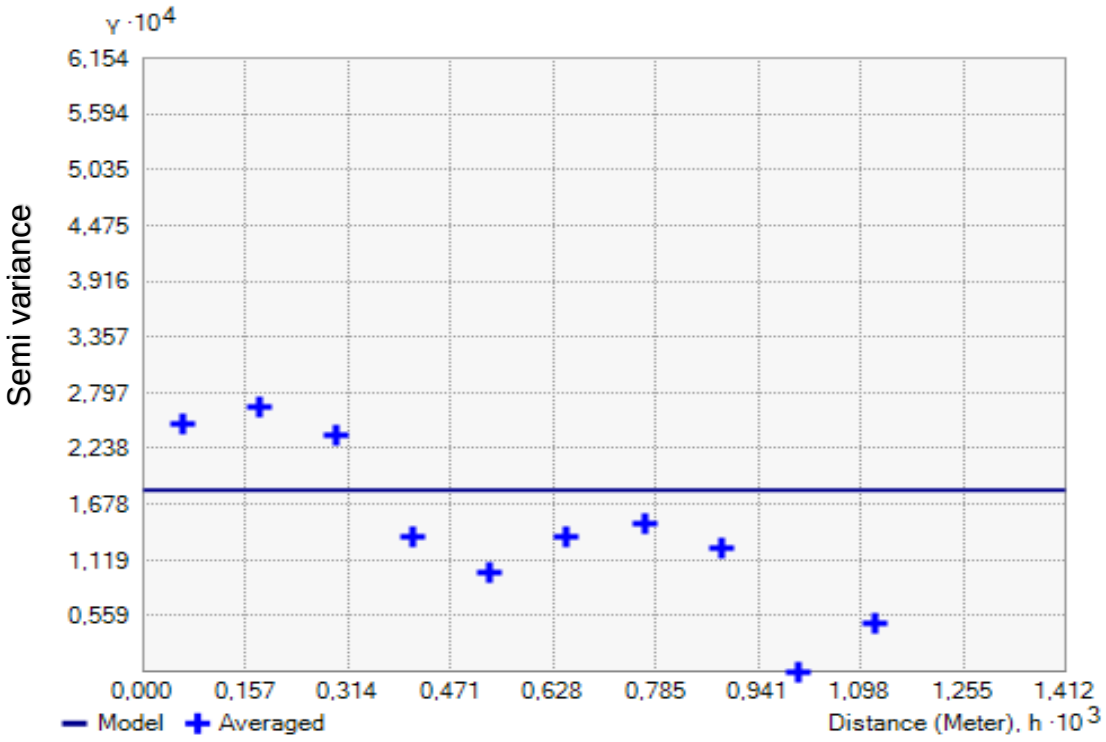


Figure 16. Kriged maps for Organic Carbon University of Venda (top) and Roodeplaat Experimental Farms (bottom)

4.1.2.3 Total Nitrogen

Exponential models were the best fit for total nitrogen at both sites (Figures 17). The Nugget to sill ratio for acid phosphatase for University Venda Experimental Farm (100%) and Roodeplaat Experimental Farm (24.39%) (Table 3). Weak and strong spatial dependence noted on University of Venda and Roodeplaat Experimental Farm with distance is thus limited to1.41e-03 and 0.02m range, beyond which there is no spatial dependence, respectively. Kriged maps for total nitrogen distribution at both sites (Figure 18). Nitrogen were more distributed on Roodeplaat Experimental Farm more than at University Venda Experimental Farm. Hence, highest and lowest total nitrogen distributions were noted on the North-South and West-East of the study site, respectively

According to the results, total nitrogen were more spatial and distributed within the field on Roodeplaat Experimental Farm (Table 3). Recent study reported moderate spatial dependence for nitrogen in an arable land and then suggested that this could be due to extrinsic factors such as land use than the intrinsic factors (Gao *et al*., 2019). Extrinsic factors such as fertilization and cultivation practices influences spatial variability of the soil properties (Wang *et al*., 2009). Application of chemical fertilisers greatly alters spatial variability of soil nutrients from the field level to the national scale and changes the relationships between soil nutrients (Roger *et al*., 2014; Shuklaa *et al*., 2016). Hence, fertilization tends to generate nitrate-leaching problems when applications are in excess of plant uptake (Venterea *et al*., 2011). Therefore, total nitrogen heterogeneity may be attributed to tillage management and application of chemical fertilisers. Total nitrogen and urease activity could be affected by the similar factors. According to the results, both total nitrogen and urease activity exhibited strong spatial variability on Roodeplaat Experimental Farm and weak was noted on University Venda Experimental Farm (Table 3). Furthermore, total nitrogen and urease distribution trends are somewhat similar. Generally, urease enzyme in the soil hydrolysis urea into ammonia and carbon dioxide.



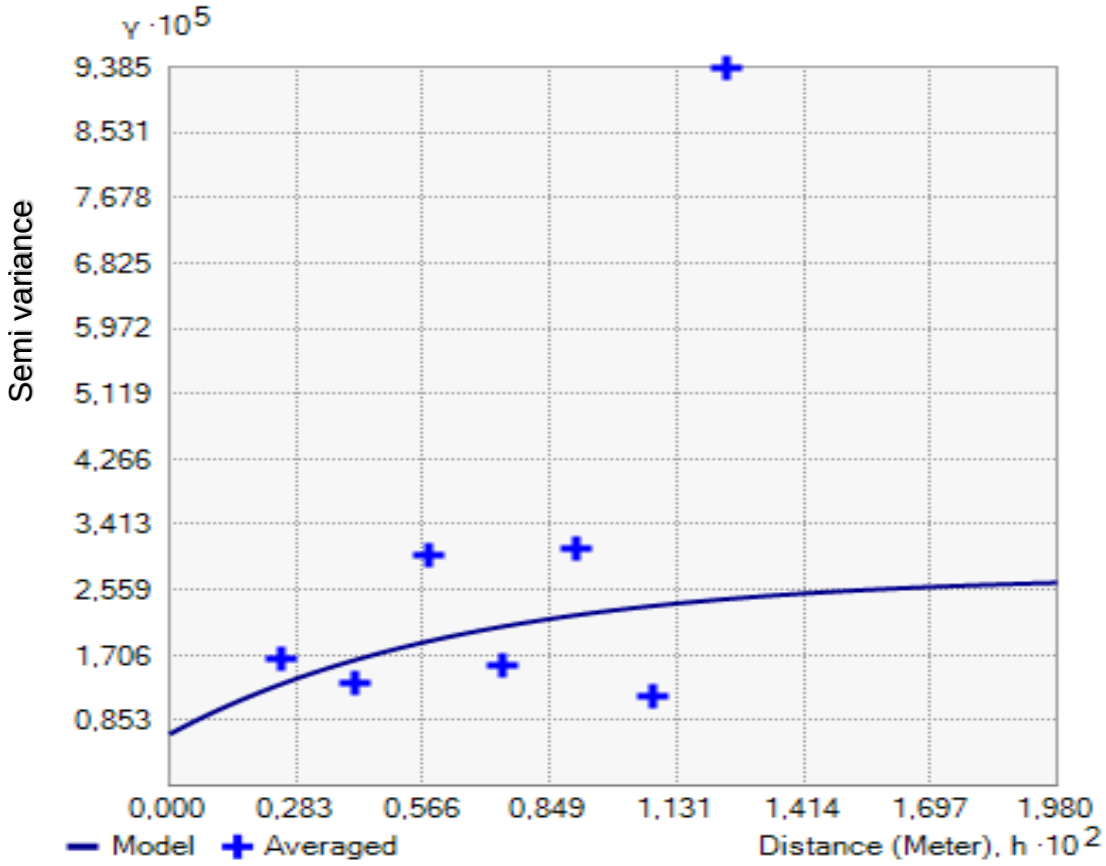


Figure 17. Total nitrogen variograms for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

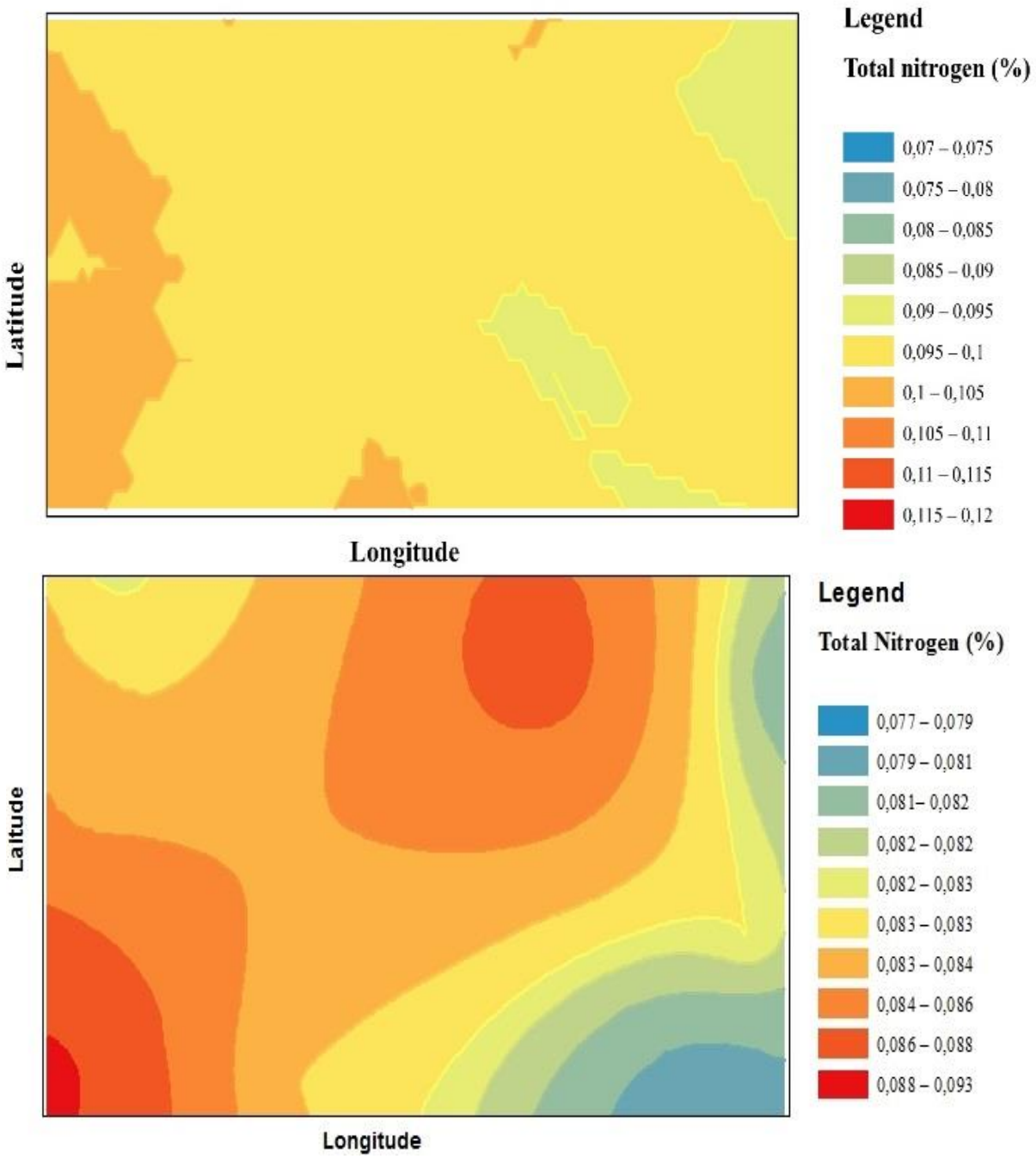


Figure 18. Kriged maps for Total nitrogen for University of Venda (top) and Roodeplaat Experimental Farms (bottom)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

The spatial variability of selected soil fertility indicators is a function of either intrinsic, extrinsic or both factors (soil forming processes, soil types, topography, soil erosion, management practices and parent materials). The selected soils were heterogeneous, which was influenced by intrinsic and extrinsic factors. Roodeplaat Experimental Farm has been intensively used for crop cultivations. Thus, spatial dependence of soil properties is due to extrinsic factors (Management practices, tillage systems and fertilizations) than intrinsic factors. For instance, the greatest spatial variability for nitrogen were noted at Roodeplaat Experimental Farm, thus could be influenced by application of nitrogen fertilisers. In arable lands, heterogeneity and variation of soil properties should be taken into consideration when implementing site-specific management. Site-specific management greatly affect spatial variability of soil properties across and within the field. However, planting and crop performance in this study were not considered. Therefore, further studies should focus the impacts of spatial variability of soil fertility indications on crop performance.

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