SPATIAL VARIABILITY OF HYDRAULIC PROPERTIES AS AFFECTED BY PHYSICAL PROPERTIES OF SELECTED SOIL TYPES IN SOUTH AFRICA

BY MARIPA MAHLODI RAMSY

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE) AT THE UNIVERSITY OF VENDA

SUPERVISOR: PROF IIC WAKINDIKI

CO-SUPERVISOR: DR AD NCIIZAH

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DEDICATION

This thesis is dedicated to my parents, France and Lisbon Maripa, who inspired me to greater ideas of life.

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I am thankful to all the people and institutions who engaged their efforts to make my Master's degree research successful. Particular words of gratitude go to my supervisors namely Prof IIC Wakindiki and Dr AD Nciizah for their commitment and unwavering support. I thank Ms B Mongwai and Dr M Marenya of the Department of Agricultural and Rural Engineering for assisting me with the mini disk infiltrometer. Further gratitude's go to Mr ZH Mabasa and Basani L, Nkuna for assisting me with GIS and soil sampling data collection. I also wish to covey special thanks to the National Research Foundation (NRF) for awarding me the Freestanding Innovation and Scarce Skills Masters Scholarship Grant number 106096. In addition, I thank the Agricultural Research Council (ARC) for awarding me the Professional Development Programme (PDP) bursary. Finally, my heartfelt gratitude goes out to my parents. Mrs Nkabe Lisbon and Mr Mashakana France Maripa and my brother Mr Khwela Claud Maripa for believing in my abilities. Finally yet importantly, I thank my late grandfather Mr Reuben Mahlodi Sehlakgoe for inspiring and encouraging me to work hard.

DECLARATION

I Mahlodi Ramsy Maripa hereby declare that the dissertation for the Master of Science degree at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other University, that it is my own work in design and in execution, and that all reference material contained therein has been duly acknowledged.

Signed…................... Date……………………………………

Supervisor: Prof IIC Wakindiki

Signed…................... Date……………………………………

Co-Supervisor: Dr AD Nciizah

Signed…................... Date……………………………………

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
AWC	Available Water Content
BD	Bulk density
CV	Coefficient of Variation
CWI	Cumulative water infiltration
GIS	Geographical information system
GPS	Global Positioning System
K	Hydraulic conductivity
Max	Maximum
Min	Minimum
NRCS	Natural Resource Conservation Service of the US
SOC	Soil Organic Matter
Std.Dev	Standard Deviation
SWC	Soil Water Content
USDA	United States Department of Agriculture
VOPI	Vegetable Ornamental Plant and Institution

PREFACE

This thesis contains six chapters. Chapter One delivers the background, objectives, problem statement and justification of the study. Chapter Two provides a general review of up-to-date literature for the research study. Chapter Three includes information about the materials and methods. Chapter Four consists of the results and discussion of the research study. Chapter Five entails the conclusions and recommendations for further studies. A list of references is provided at the end.

ABSTRACT

Soil hydraulic and hydraulic-related physical properties are key to soil productivity and these properties are widely studied. Nevertheless, their spatial variability is least understood. Two sites were selected for this study (University of Venda Experimental farm and Roodeplaat, Agricultural Research Council farm). The objectives of this study were to determine the spatial variability of soil water content, water infiltration and hydraulic conductivity on selected soils. Field measurements were done on a 20 m × 20 m. Soil hydraulic and hydraulic-related physical properties were studied at two depths, 0 – 0.2 m top soil and 0.2 – 0.4 m sub soil. The field was irrigated to saturation and let to drain freely for two days. The soil was quickly secured in water cans to avoid further loss of water by evaporation and taken to the laboratory for analysis. Data was analysed using ordinary kriging method in ArcMap® software version 10.4 to generate spatial variability maps and semi variograms. The University of Venda Experimental farm had lesser spatial variability with coefficient of variation ranging from 9.6 to 33.4%. The spatial variability of soil was very low confirmed by contour maps depicting slightly homogeneity. Whereas, the soil hydro-physical properties displayed greater spatial variability at Roodeplaat, Agricultural Research Council Experimental farm. The empirical variograms of spherical model fits were also assuming weak spatial dependence with a curve variogram. The coefficient of variation ranged from 10.5 to 51.9%. Therefore, the greater variability at Roodeplaat, Agricultural Research Council Experimental farm indicated that coarse soil texture under conventional tillage has a greater influence on the spatial variability of the soil hydro-physical properties.

Keywords: Semi-variogram, kriging, mini disk infiltrometer, hydraulic conductivity, infiltration.

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Knowledge of soil hydro-physical properties is necessary for addressing matters related to sustainable management of soil and water resources to sustain water efficiency (Hillel, 2012). They include water status parameters namely soil water content (SWC), cumulative water infiltration (CWI) and hydraulic conductivity (K). Hydrologic- related soil physical properties are soil texture, soil organic matter (SOM) and bulk density (BD). Soil water retention is crucial to water movement in soil and water. The soil is functionless without water since the soil hydraulic properties manage transportation processes and water balance in soils.

Although soil water status is significant in agriculture, it is never uniform in a given field. Altieri (1999) found that plant residue decomposition created favourable conditions for water movement and infiltration on top soil, the soil water retention was always higher on the sub soil. The spatial variability of SWC, water infiltration and hydraulic conductivity is needed for adoption of agricultural field trial research and precision agriculture (Bouma et al., 1999). The results will be advantageous for soil mapping, site-specific management of soil properties, developing appropriate land use plans and quantifying anthropogenic impacts on the soil system (Rosemary et al., 2017).

Therefore, it is important to study hydro-physical properties in both top- and sub-soil. The assessed spatial variability of soil properties in areas under different land use reported that soil characteristics were significantly heterogeneous in native land but homogeneous in cultivated land (Outeiro et al., 2008; Kilic et al., 2012; Rosemary et al., 2017). Therefore, it is vital not to assume field homogeneity in every agriculture field. In many cases, the spatial variation of hydro-physical soil properties is ignored because soil tests are based on composite samples (Romano, 2014). Therefore, there is need to study the spatial variability of hydro-physical soil properties in both top- and sub soil in South Africa (Neves et al., 2017). Moreover, soil infiltration and other hydro-physical properties are essential in improving irrigation water use efficiency, water availability for plant uptake and soil organism’s metabolism (Haghnazari et al., 2015).

1.2 Problem statement

Many soil studies are based on composite samples that are collected from a large area. However, such sampling strategy ignores the inherent spatial variability of natural soils or the influence of extrinsic factors such as soil use and tillage. Heterogeneity and variation of soil physical parameters exists due to continuation of cultivation in the field (Gulser et al., 2016). Therefore, when designing studies to explicitly explore spatial variability, the spatial sampling design needs to be wisely considered, which includes the consideration of where to sample, how many locations to sample and how much data to collect at each sampled location (Stanton, 2017).

1.3 Justification

Information of spatial variation of soil properties is crucial for precision farming and environmental protection. For example, knowledge of the spatial variability of soil hydro-physical characteristics such as water infiltration, hydraulic conductivity and water content can be used to determine site-specific land use management and water use. Evidence on soil spatial variability of soil properties is essential for agricultural land assessment and also to support soil management resolutions such as selecting the appropriate fertilizer dose, application methods and frequency, and the improvement of soil drainage (Acheampong and Silva, 2015).

1.4 Aim and Objectives

1.4.1 Aim

The aim of this study was to make a contribution to the understanding of the nature of spatial variability of soil hydro-physical properties in selected South African soil types.

1.4.2 Objectives

1) To determine the spatial variability of soil water content on selected soils.
2) To determine the spatial variability of cumulative water infiltration on selected soils.
3) To determine the spatial variability of hydraulic conductivity on selected soils.

1.5 Hypotheses

1. There is spatial variability of soil water on the selected soils.
2. There is spatial variability of water infiltration on the selected soils.
3. There is spatial variability of hydraulic conductivity on the selected soils.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Spatial variability of soil hydro-physical properties

Spatial variability of hydro-physical soil properties is an indicator of soil water status and related properties over distance (Iqbal, 2005). This variability is mostly recognised in both topsoil and sub-soil through determination of soil water characteristics, soil texture, soil organic matter (SOM) and soil bulk density (Arshad and Coen, 1992).

2.2 Soil texture effects on soil water content, cumulative water infiltration and hydraulic conductivity

Price et al. (2010) studied soil hydraulic properties across land uses and reported that soil texture caused great variation in other soil properties especially when the soil was developed from different parent material. Moreover, Perrier et al. (1996) reported that soil texture alters soil water retention and distribution depending on pore space geometry. Haghnazari et al. (2015) who explained that soil characteristics such as soil texture supported this observation, strongly affect the hydraulic conductivity through its effect on soil macro and micro-pores. In addition, water infiltrates faster through the macropores than it does through small pores. Spatial variability of soil texture is greater on coarse textured soil with large macropores since it allows percolation and transmission of water to unsaturated soil quickly (Mohanty et al., 2017).

It is commonly observed that large pores improved infiltration in coarser textured soil and there is less runoff on unsaturated soil. However, clay soils have more micro pores and high water-holding capacity especially in the presence of cracks and conduits for directing water to unsaturated soil. Moreover, the nature of clay minerals may influence the capacity of soil to hold water depending on the capability of soil to swell

(Wakindiki and Ben-Hur, 2002). In addition, the increase in soil depth was found to increase soil texture variation (Vaysse and Lagacherie, 2015). However, the variation is less when soils are developed from same parent material (Vaysse and Lagacherie, 2015).

2.3 Soil organic matter effects on soil water content, cumulative water infiltration and hydraulic conductivity

SOM plays an important role in improving water infiltration and percolation because it improves soil structure, stabilization of aggregates and pore-size distribution (Ekwue et al., 1990; Rockström et al., 2010). It is agreed that the decrease in SOM also reduces water infiltration and increases soil bulk density. Studies have exposed that a 1% rise in SOM can increase the SWC within the available water holding capacity range depending on the type of soil texture (Hudson, 1994). The US Natural Resource Conservation Service (NRCS) soil survey characterization database has supported the above statement since they reported that a 1% rise in SOM can result in a 2% to 5% rise in available water holding capacity (Saxton and Rawls, 2006).

According to (Baumhardt and Lascano, 1996) litter that fall on the forest soil increase hydraulic conductivity compared to cultivated soils. Since, when decomposition takes place SOM significantly develop good soil structure and improve water holding capacity and increase available water content (AWC) (Hudson, 1994); (Johnson et al., 2005) found that in about 60 surface samples containing three texture groups: sands, silt loams and silty clay loams, organic matter increased from 0.5% to 3%. They also found that for every percent increase in SOM weight between 1 to 4%, AWC increased 0.022, 0.037 and 0.028 % respectively.

According to Don et al. (2007) the variability of SOM concentration is caused by different factors, which lead to distinct vertical pattern of variability. The variation was found to be twice as high on the top- soil compared to the sub- soil. In other terms, SOM was 10 % on the top- soil and 1% in sub- soil (Hobley and Wilson, 2016). Since the plant litter and dead animal material are found on the soil surface, SOM is higher in the top- soil. Therefore, the SOM content decreases with increasing depth from the soil surface. The SOM decomposition affects the physical properties of the soil. Fully decomposed organic material into humus can increase water holding capacity by 44.3% in clay soil and 28.3 % in quartz sand through improved soil aggregation (Troeh and Thompson, 2005).

2.4 Soil bulk density effect on water content, infiltration and hydraulic conductivity.

Bulk density reflects a soil's capability to function for physical support, solute movement, root penetration and soil aeration (Green et al., 2003). An increase in soil bulk density linked to compaction has a dramatic impact on soil hydraulic properties and as such can have significant effects on water flow and transport processes (Green et al., 2003). According to Horton et al. (1994) high bulk density conditions usually increase with depth due to reduced pore space on the sub soil as an outcome of soil pressure. However, the saturated hydraulic conductivity decreases with increasing bulk density as a response of the smaller volume of coarse pores in compacted samples. Furthermore, a rise in soil bulk density above 1.6 g/cm^3 is a display of soil compaction which mostly increases with depth (Lenhard, 1986).

The spatial variability of soil bulk density is often created through alteration of land use and practice of agricultural activities (Gifford and Roderick, 2003). For example, soil bulk density varies if land changes from fallow to cultivated (Bielders et al., 2002). Moreover, soil bulk density of cultivated soils differs in space depending on type of tillage practiced (Alletto and Coquet, 2009). Top soil and sub soil were found to vary from 0.96 to 1.52 g/cm^3 and from 1.24 to 1.43 g/cm^3 under conventional tillage respectively (Alletto and Coquet, 2009).

2.5 Spatial variability of soil water content

Soil water plays an important role in controlling hydrologic processes and water cycle (Wang et al., 2016). The SWC influences the atmosphere through the initiation of evaporation, evapotranspiration, sub-surface transport of pollutants. the timing of irrigation. and rainfall-runoff transformation (Morbidelli et al., 2016).

Spatial variability of SWC reflects how soil water varies over distance and depth (Iqbal, 2005). For example, Kilic et al. (2012) found a minimum variation on water content at a distance of 20 m x 20 m. Moreover, they also reported that soil properties changes in relation to the duration of soil tillage.

According to Wang et al., (2001) outcomes on the soil water patterns based on five depths (0-5, 15-20, 25-30, 45-50 and 70-75) reported a change in spatial dependence over time and depth. Therefore, the results deliver awareness of variability of SWC on large scale and interpolation strategies for extrapolating point measurements across the field.

The SWC was found to be highly variable in space and time, and its variability results from many process operating at a wide range of scale is influenced by soil type and texture (Wang et al., 2001). Moreover, the spatial and temporal variability in soil water content soil showed the uneven water patterns in water repellent sand, loam, clay and peat soils with grass cover. Thus, the spatial variability in SWC under grass cover remained high due to fingered flow on arable land, vegetation and micro topography appeared to play a dominant role (Dekker and Ritsema, 2000).

According to a study by Wang et al. (2001) SWC had high sills ranging from 4.6-14 % and high range of 135-160 m during dry conditions. However, the sills 2.6 - 6.3% and ranges 140 m were found to be lesser during wet conditions (Wang et al., 2001).

Moreover, it is recognised that the layered-averaged soil water of the sill increases with depth, but not for the ranges (Prendergast et al., 2018).

According to Wang et al. (2016) the value of nuggets tends to rise with higher sills. The positive nugget result of SWC varied from 0.07 to 0.52. It was attributed to the sampling error, short-range variability, random and inherent variability. They also found that nugget variance to sill at below 25% during dry and rainy seasons lead to strong spatial dependence of SWC on the field. Moreover, Cambardella et al. (1994) recommended that the soil variables with stronger spatial dependence can be explained by the intrinsic variability of soil, while the weaker spatial dependence can be explained by extrinsic variability.

2.6 Spatial variability of water infiltration

According to Lennartz et al. (2009) water infiltration spatial variability is strongly influenced by soil compaction. Compacted soil results in reduced soil porosity and restriction of water movement. The infiltration process into soils is controlled by a function of soil properties such as water content, hydraulic conductivity, texture, organic matter and bulk density (King, 1992). Although these factors are not complete, they are illustrative of the major dynamics that direct the infiltration process (King, 1992).

The rate at which water penetrates soil cannot exceed the rate at which water is transmitted through the soil profile. Hillel (2012) supports this assertion by commenting that surface entry conditions alone cannot improve infiltration unless the transmission capacity of the soil profile is acceptable. Moreover, Cousin et al. (2003) reported that where the surface-entry is relaxed, both the transmission and infiltration rate becomes partial within the soil profile and this is mostly seen on high compacted soil. Meanwhile Buol et al. (2011), observed that with good land management water infiltrates faster due to more room available for additional water on the soil surface. Hence (Shanafield and Cook, 2014) reported that infiltration rates rise as transmission rate rises.

Spatial variability of infiltration capacity is essential higher in run-off generating areas (especially in semi-arid regions) where infiltration exceed the initiation of run-off development process (Bracken and Croke, 2007). The water that does not infiltrate becomes overland flow on slopes. The final result in terms of net water losses is highly scale dependent (Daryanto et al., 2013).

The spatial variability of infiltration influences the run-off initiation, this has been reported when runoff dynamics become important and vary at the hillslope scale. For example, overland flow may be generated from some areas on the hillslope solitary to infiltrate the soil somewhere downslope (Wilcox et al., 2017). Spatial variability of infiltration is generally higher under shrub canopies than inter-canopies areas. The run on from the inter-canopy patches often contributes additional water to the shrubs patches (Breshears and Barnes, 1999; Bhark and Small, 2003). Moreover, these differences markedly influence the pattern of SWC.

Reza et al. (2016) on a study of spatial distribution of soil physical properties of alluvial soils, indicated that all the measured soil properties are moderately spatially dependent with nugget/sill ratio of (37–70%) including water infiltration. Moreover, it was shown that the estimation of soil physical properties by means of semivariogram parameters is improved on cross-validation of the krigged map than assuming mean of observed value for any un-sampled location (Reza et al., 2016). The nugget over sill (N/S) ratio directs the spatial structure of data and defined three classes (strong spatial structure ≤ 25%. moderate 25-75% and low ≥75%).

Moreover, it is recognised that the values of any neighbouring points assume that properties that are closer in distance are similar however, this condition is effective only in small scale measured soils (Secu et al., 2015). Although (Reza et al., 2016) found all properties to be moderate and spatially dependent. (Greenholtz, 1988) reported all properties to have large spatial variability both horizontally and vertically in the field.

2.7 Spatial variability of hydraulic conductivity

Saturated hydraulic conductivity refers to quantitative measure of soil's ability to transmit water when subjected to a hydraulic gradient. According to Logsdon and Jaynes (1996), the hydraulic conductivity depends strongly on the arrangement of the soil pores. For instance, the macro pores of sandy soil allow water to move quickly through unsaturated soil and lead to high hydraulic conductivity whereas, micropores of clay soils permits water to move slowly resulting in low hydraulic conductivity. However, the soil pores arrangement from a cultivated field were reported to vary temporally because of the settling of particles created by tillage (Azevedo et al., 1998).

It has been reported that texture of clay particles takes time to settle because of the light grain size particles whereas, sand particles take less time to settle (Bouyoucos, 1962; Loveland et al., 2000). Extrinsic and intrinsic factors account for the variation of hydraulic properties from field to field in a watershed (Diiwu et al., 1998). According to Diiwu et al. (1998) and Gupta et al. (2006) field saturated hydraulic conductivity is highly correlated than other soil physical characteristics. They also found that saturated hydraulic conductivity displays more spatial variation along the field slope than across the field slope. However, Mulla and McBratney (2002) showed that saturated hydraulic conductivity typically displays short-range variability.

Moradi (2012), found a weak spatial correlation with a nugget of 12.95 partial sill of 15.9% and semi variogram model error (C0/Sill) of 81% in semi variogram of hydraulic conductivity. However, Mulla and McBratney (2002) showed that saturated hydraulic conductivity typically displays short-range variability.

2.8 Spatial variability of soil structure

According to Mueller et al. (2003), the spatial variability of soils is one of the main sources of structural loss and the disfunctioning of built systems. Moreover, cultivation of soil reported to cause alterations on soil structure and hydraulic properties dynamically in space and time (Shanafield and Cook, 2014). According to Lacoste et al. (2016), the problem of inventorying spatial variability of soil structure was therefore reduced to mapping the thickness and depth of functional layers. The correct forecast of these structural consequences requires (Bauduin, 2003).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Description of the study sites

Two sites were selected for this study. The first site was at the University of Venda Experimental farm. This site is about 22.9761° S, 30.4465° E and 596 m above sea level. The 14 ha farm is located about 2 km west of Thohoyandou town in Limpopo Province and the farm was previously used for animals grazing. The farm is characterized by deep well drained Hutton soil form (Soil Classification Working Group, 1991) or rhodic Ferralsol (FAO, 2016). The field is on 8% gently undulating slope running in a North-South direction (Mzezewa and Van Rensburg, 2011). Rainfall is highly seasonal with 85% occurring between October and March during the summer. The mean maximum temperature is 30 ºC while the mean minimum temperature is 20 ºC. The highest evaporative demand occurs from October to March. The area falls on a semi-arid climate and the average rainfall is about 780 mm (Mzezewa and Van Rensburg, 2011).

The second site was at the Roodeplaat Agricultural Research Council (ARC) farm. The farm is at 25.6014° S, 28.3603° E; 1168 m and continuously used for agricultural research purposes. The farm is characterized by sandy clay loam soil classified as Clovelly soil form (Soil Classification Working Group, 1991) or Cambisols / Luvisols (FAO, 2016). The average rainfall within a season is 500 mm but is highly variable with maximum precipitation in December and January. Daily maximum and minimum temperature averages are 34 °C and 8 °C with long hot and rainy summers and short cool and dry winters. The area falls on a moderately dry subtropical climate, specifically a humid subtropical climate. Figure 1 shows both the study sites in South Africa.

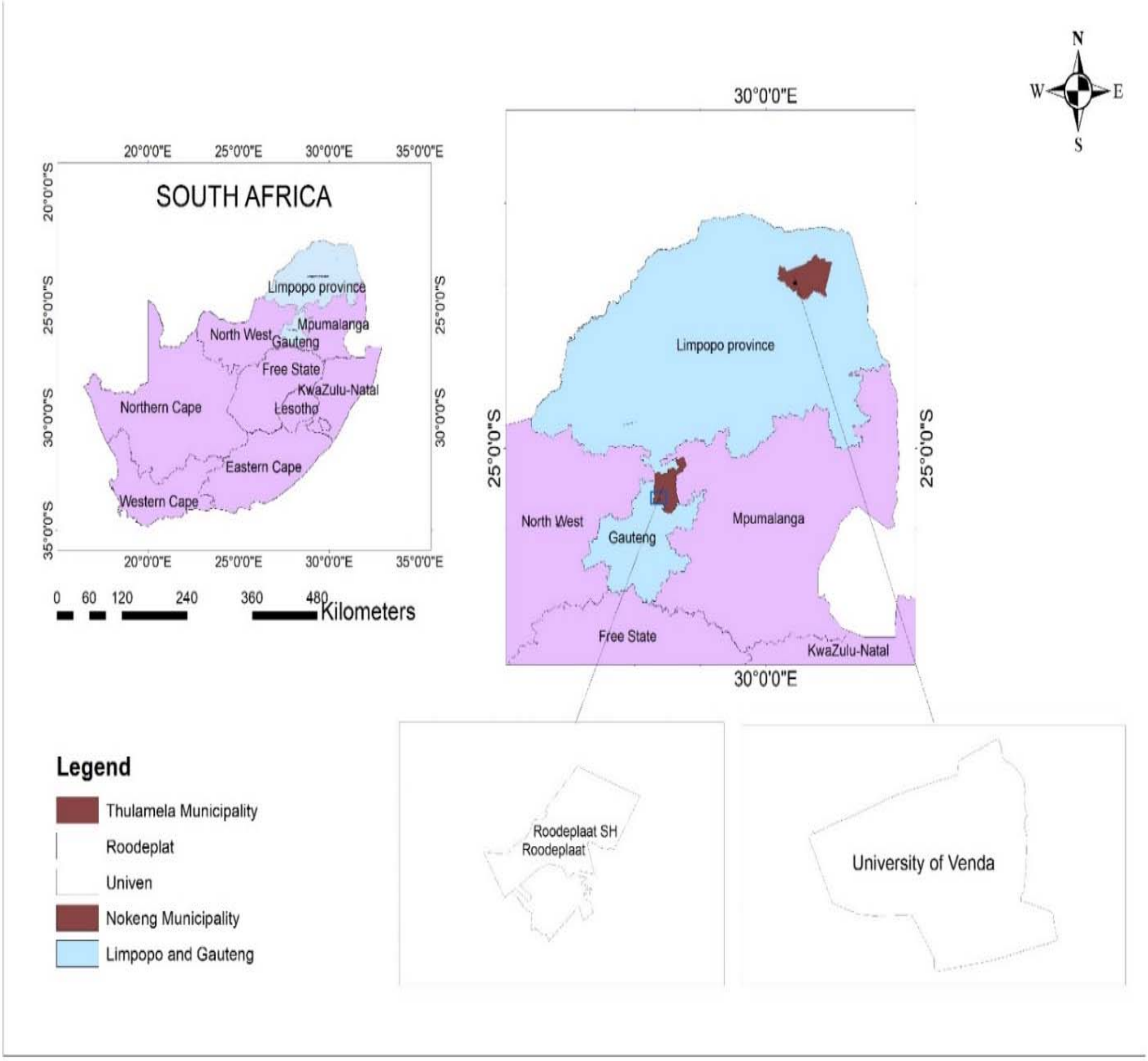

Figure 1. Location of University of Venda and Roodeplaat Agricultural Research Council Experimental farms

3.2 Land preparation and soil sampling.

The study sites were prepared uniformly using a mouldboard plough and disc harrow from March-September 2018. The study areas were demarcated using wooden pegs and nametags for identification of sampling points in each site. A field of ~1 ha size was divided into 12 grid cells of 20 m × 20 m distance using a tape measure. The soil sampling points were georeferenced-using GPS at a distance of 20 m across one grid cell to another. This sampling procedure was adopted from Kilic et al. (2012). The field was irrigated to saturation and let to drain freely for two days. On the third day, 24 soil samples were taken from top and sub soil across the 8% slope using a core sampler. Two soil samples were taken on one grid from 0 - 0.2 m and 0.2 - 0.4 m. Figure 2 and 3 are sketches of the field sampling point's layout at each respective site.

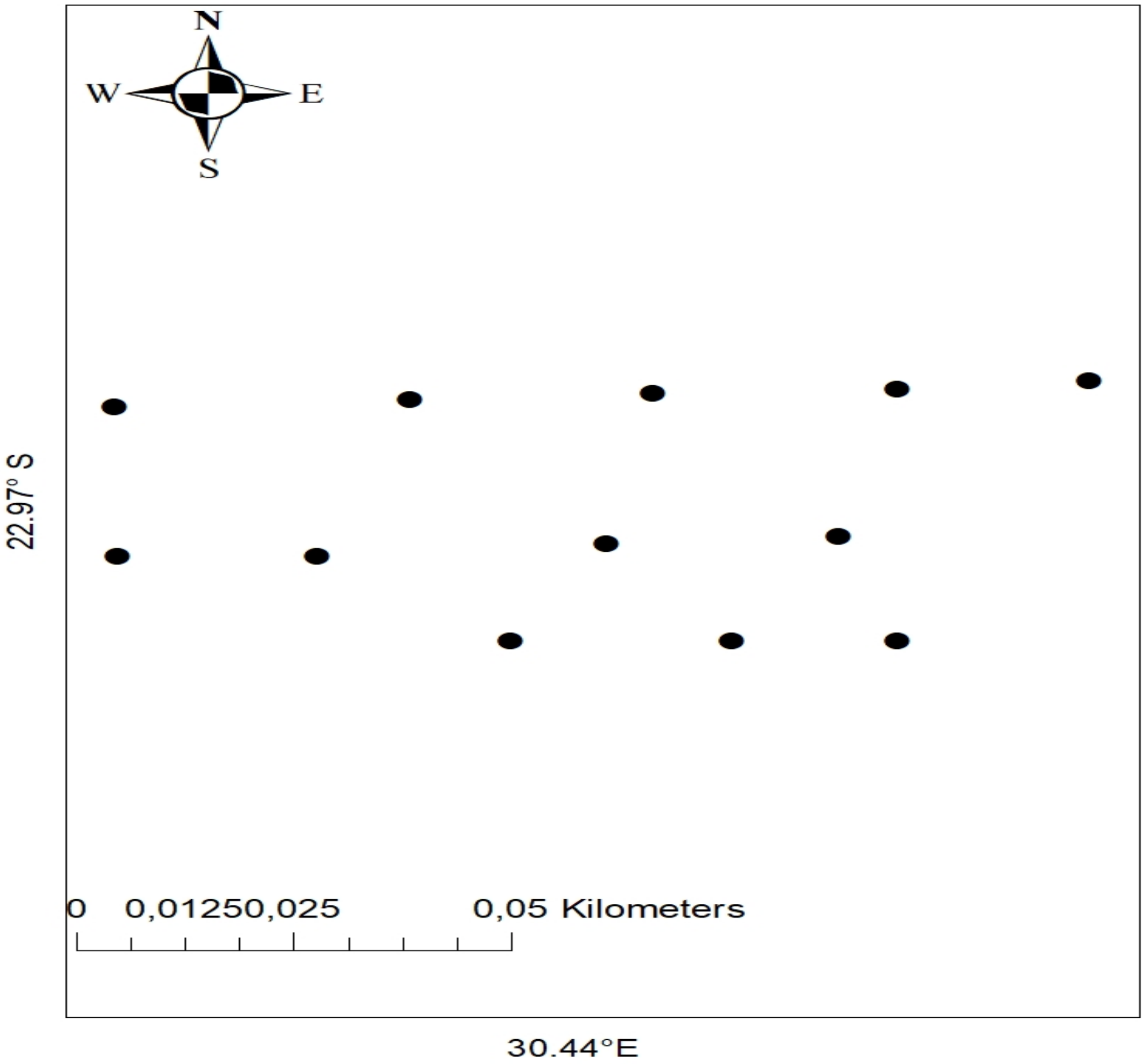

Figure 2. Soil sampling points at the University of Venda Experimental farm.

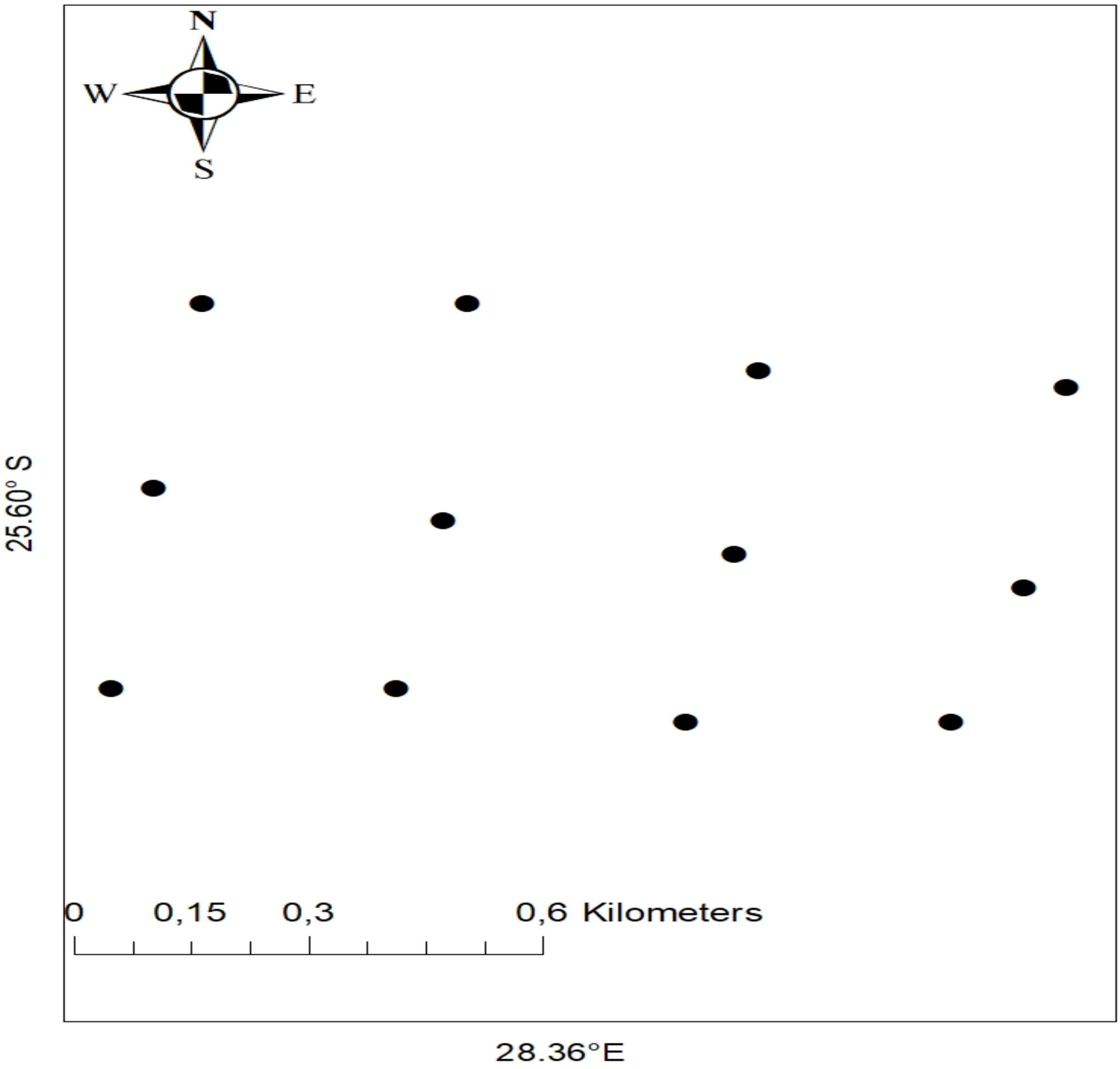

Figure 3. Soil sampling points at Roodeplaat Agricultural Research Council Experimental farm.

3.3 Soil water content

A core sampler with cylindrical soil cores of 8 cm diameter and 5 cm height was used to collect undisturbed soil samples. The soil was quickly secured in water cans to avoid further loss of water by evaporation and taken to the laboratory for analysis. This exercise was repeated three more times. Each time, the soil samples were obtained from 0 to 20 cm and 20 to 40 cm. The SWC analysis was determined following the gravimetric method (Grossman and Reinsch, 2002). Fresh mass of soil sample was recorded before placing the core in the oven to dry for 24 h at 105 ºC. The mass of samples was recorded again after oven drying. The amount of soil water was expressed using Equation 1.

$$\theta_v = \left(\frac{m_w}{m_s}\right)\rho_b \qquad [1]$$

Where the θ_v = mass of wet soil m^3/m^3.

m_w = mass of water kg

m_s = mass of dry soil solids kg

ρ_b = bulk density kg/m^3

3.4 Cumulative water infiltration and hydraulic conductivity

Immediately after soil sampling for soil water determination, infiltration test was done using a mini disk infiltrometer (Decagon Devices, 2011). The instrument allows water to infiltrate under tension to prevent the filling of the macropores. Water flow in macropores was eliminated by keeping the suction at 0.02 m (Decagon Devices, 2011). A thin layer ~3 mm of silica sand was applied to the surface to smoothen it and give good contact between the soil surface and the infiltrometer. The infiltration test was started by recording the initial volume of the water in the reservoir. Thereafter, readings of the remaining volume of water in the reservoir were taken from 30 s intervals until 95 mL had infiltrated as recommended by the manufacturer (Decagon Devices, 2011). Cumulative infiltration was estimated as proposed by Zhang et al. (1997) in Equation 2.

$$I = C_1 t + C_2 \sqrt{t} \qquad [2].$$

Where I = Cumulative infiltration m^3

C_1 = parameter related to the hydraulic conductivity (m/s)

C_2 = soil sorptivity $m/s^{0.5}$

t = was the time interval (s)

I and √t were obtained using the basic Microsoft Excel® spreadsheet developed by (Decagon Devices, 2011).

3.5 Soil texture

The particle size distribution was determined following the hydrometer method (Bouyoucos, 1962). This method quantitatively determines the physical proportions of three sizes of primary soil particles as determined by their settling rates in an aqueous solution using a hydrometer. Proportions are represented by class sizes: - sand ranging from 2000 – 50 µm; silt ranging from 50 – 2.0 µm and clay < 2.0 µm. Settling rates of primary particles are based on the principle of sedimentation as described by Stokes' law and measured using a hydrometer. Destruction of the SOM was done with hydrogen peroxide and dispersion with sodium hexa-metaphosphate. The SOM was destroyed in a 70 g soil sample by applying successive aliquots (approximately three times) of 40 mL of hydrogen peroxide (H_2O. 130 volumes) until the effervescence of the reaction was minimal. The procedure was performed on an 80 ºC hotplate. The oxidized samples were placed in a forced-air oven and allowed to dry-off at 80 ºC. Dispersion was obtained by shaking 50 g of dry soil sample with 100 mL of 25%

sodium hexa-metaphosphate for 16 hours in a reciprocating shaker. The mixture was then placed in a Bouyoucos' blender cup and stirred for two minutes with an electrical mixer. The contents of each cup were transferred to a 1 L sedimentation cylinder and the cylinder was filled with deionized water to the 1000 mL mark. The mixture was then homogenized using manual agitation. The solids in the suspension were measured with a hydrometer following 40 seconds of decantation with a second readings taken after six hours. The measurement was made when the suspension was between 20 and 22 °C and then corrected for temperature. The first reading was for estimating the clay content whereas the second one at six hours was to estimate the silt content (Bouyoucos, 1962). The sand fraction was calculated as the difference between those two measurements. The various soil texture fractions were calculated using Equations 3 4 and 5.

Percent clay

% clay = corrected hydrometer reading at 6 hrs. 52 min. x 100/ wt. of sample [3]

Percent silt

% silt = corrected hydrometer reading at 40 sec. x 100/ wt. of sample -% clay [4]

Percent sand

% sand = 100% - (% silt - % clay) [5]

3.6 Soil Organic Matter

The organic material reported to oxidize with a hot mixture treatment of sulphuric acid (Walkley and Black, 1934); below is the Equation: -.

$$2Cr_2O_7^{2-} + 3C + 16H^+ - 4Cr^{3+} + 3CO_2 + 8H_2O \quad [6]$$

After the completion of the reaction, the excess dichromate was titrated with iron (II) ammonium sulphate hexahydrate. The reduced dichromate was assumed to be equivalent to the organic C present in the sample assuming that the SOM has an average valence of zero. Organic matter was estimated as organic carbon content following Walkley and Black (1934) method. Organic carbon content was calculated following Equation 7.

$$Organic\ C\% = \frac{[cm^3\ Fe\,(NH_4)_2(SO_4)_2\ blank - cm_3\ Fe\,(NH_4)_2(SO_4)_2\ sample]\ x\ M\ 0.3\ x\ f}{Soil\ mass\ (g)} \qquad [7]$$

3.7 Soil Bulk Density

Soil bulk density was determined following the core method (Grossman and Reinsch., 2002). The cylindrical soil cores of 8 cm diameter and 5 cm height were used to collect soil by applying pressure on undisturbed soil samples. Soil samples were taken as close as possible to the hydraulic conductivity measurement sites. Soil cores were dried in an oven at 105 °C for 48 h until constant weight. Therefore, bulk density ρ_b (g/cm^3) was expressed using Equation 8.

$$\rho_b = \frac{m_s}{v_t} \qquad [8]$$

Where, ρb = bulk density, kg/m^3

m_s = mass of solids, kg

V_t = total volume, m^3

3.8 Data Analysis

The soil spatial variability data were interpolated using ordinary kriging method (Webster, 1996). Soil spatial variability maps were created using ArcMap10.4 software (Fischer and Getis, 2009). Semi-variograms were obtained from semi variances γ (h) of each set of spatial observations calculated as follows: -

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(xi + h) - z(xi)]^2 \qquad [9]$$

Where

γ (h) was the experimental semi variogram.

N was the number of pairs separated with lag distances h

Z was the measured values at location z (xi) and z (xi+h) respectively.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Soil hydro-physical properties at the University of Venda Experimental farm.

Soil water status parameters at the University of Venda Experimental farm and their descriptive statistics are shown in Table 1 and 2 respectively. The SWC in the top soil was ~ 30% less than that in the sub soil. Nevertheless, it was more variable in the top- compared to the sub soil (Table 1 and 2). It is also recognized that volumetric moisture content increases with increase in depth. This implies that the soil has capacity to hold more water and can be stored for a longer period on the soil profile. Water infiltration was ~ 1 L after an hour and hydraulic conductivity was similar to that of silty sand material (Table 1).

Table 1. Soil water status parameters at the University of Venda Experimental farm

	Soil Water content, (%)		Water Infiltration, (m^3)	Hydraulic conductivity, (m/s)
Grid	Top soil	Sub soil	× 10^{-4}	× 10^{-4}
1	28.3	36.0	3.2	1.9
2	24.5	32.4	4.6	2.2
3	32.9	37.4	2.2	1.6
4	26.8	28.4	3.5	2.1
5	26.5	31.4	5.8	3.2
6	25.4	30.5	6.2	6.9
7	25.2	30.0	6.5	6.5
8	24.1	30.3	7.4	6.2
9	25.9	33.1	6.8	4.6
10	29.3	31.2	3.8	3.0
11	26.9	31.1	3.0	2.3
12	22.5	31.7	4.1	3.2

Table 2. Descriptive statistics for soil water status parameters at the University of Venda Experimental farm

	Soil Water Content (%)		Water Infiltration (m^3)	Hydraulic conductivity (m/s)
	Top soil	Sub soil	Top soil	Sub soil
Min	22	28	2.2 x10^{-4}	1.6 x10^{-4}
Max	35	60	7.4 x10^{-4}	6.9 x10^{-4}
Mean	29	41	4.7 x10^{-4}	3.6 x10^{-4}
Std. Dev	0.4	0.12	1.7 x10^{-4}	1.9 x10^{-4}
CV, (%)	18.3	16.8	25.96 x 10^{-1}	3.08 x 10^{1}
Kurtosis	1.77	1.71	1.61	1.92
Skewness	0.27	0.7	1.3 x 10^{-1}	6.9 x 10^{-1}

Table 3 and 4 contains results for the hydraulic related soil physical properties and their descriptive statistics. The soil texture was uniform across the sampling area (Table 3). The mean BD was 1200 kg m^{-3} (Table 4), close to the average BD of a typical mineral soil, which is 1350 kg m^{-3} (Hillel, 1980). The results showed that soil bulk density increase with an increase in depth. According to (Lal, 2006), the normal range of bulk densities for clay soil is 900 to 1400 kg/cm^{-3} and a normal range for sandy soil is 1400 to 1900 kg/cm^{-3} ,with potential root restriction occurring at greater or equal to 1400 kg/cm^{-3} for clay and greater or equal to 1600 kg/cm^{-3} for sand.

The SOM was ~ 50% more in the top- compared to sub soil. The effect of soil texture on SWC was uniform across the sampling area. Conversely, an increase in SOM increases SWC within the available water holding capacity range depending on the type of soil texture (Hudson, 1994; Saxton and Rawls, 2006). The higher content of organic matter in Univen is the results of the high amount of plant residue found on the soil surface. In addition, (Swanepoel et al, 2016) reported that soil organic matter (SOM) is strongly linked to soil quality, but cultivation normally causes a decline in both SOM and the soil quality. This implies that the University of Venda soils has better soil quality and productivity. Therefore, the influence of the silt clay loam texture and its mineralogy need further investigation.

Table 3. Soil texture, bulk density and organic matter at the University of Venda Experimental farm

	Soil texture class		Bulk density ($\times 10^3$ kg/m^3)		Soil organic carbon (%)	
Grid	Top soil	Sub soil	Top soil	Sub soil	Top soil	Sub soil
1	Silty clay loam		1.46	1.53	0.92	0.24
2			1.24	1.52	1.33	0.82
3			1.43	1.63	1.41	0.31
4			1.62	1.66	0.85	0.64
5			1.55	1.57	0.54	0.35
6			1.46	1.48	1.44	0.59
7			1.25	1.26	1.22	0.39
8			1.30	1.40	1.17	0.35
9			1.43	1.50	0.6	0.29
10			1.19	1.28	0.96	0.41
11			1.41	1.72	1.26	1.14
12			1.52	1.64	0.61	0.13

Table 4. Descriptive statistics for bulk density and soil organic matter at the University of Venda Experimental farm

	Bulk Density ($\times 10^3$ kg/m^3)		Soil organic carbon (%)	
	Top soil	Sub soil	Top soil	Sub soil
Min	0.89	1.01	0.54	0.13
Max	1.23	1.37	1.55	1.14
Mean	1.08	1.20	1.03	0.47
Std.Dev	0.11	0.13	0.33	0.28
CV, (%)	9.55	9.57	27.03	33.37
Kurtosis	1.76	1.56	1.73	3.62
Skewness	0.26	0.22	0.13	1.17

4.2 Soil hydro-physical properties at Roodeplaat Agricultural Research Council Experimental farm

Soil water status parameters at the Roodeplaat Agricultural Research Council Experimental farm and their descriptive statistics are shown in Table 5 and 6 respectively. The SWC in the top- and sub soil was approximately equal. Nevertheless, it was more variable in sub- compared to the top soil (Table 5 and 6). The contour maps portrayed high spatial variability over grid points and the variation was observed when the soil water content varies with space on the same field.

Table 5. Soil water status parameters at the Roodeplaat Agricultural Research Council farm

Grid	Soil Water Content, (%)		Water Infiltration, (m^3)	Hydraulic conductivity, (m/s)
	Top soil	Sub soil	$\times 10^{-4}$	$\times 10^{-4}$
1	31.4	35.6	2.1	2.5
2	21.9	28.9	2.39	2.8
3	20.6	23.9	1.21	1.8
4	26.1	30.1	1.47	3.8
5	19.4	24.9	1.54	2.5
6	20.7	24.6	1.44	1.6
7	18.9	24.6	1.33	1.2
8	18.5	20.4	1.68	1.5
9	20.6	30.7	1.15	1.5
10	16.9	32.7	1.28	1.3
11	22.2	34.1	1.36	1.4
12	25.6	33.0	1.16	1.4

Table 6. Descriptive statistics for soil water status parameters at the Roodeplaat Agricultural Research Council Experimental farm

	Soil water content (%)		Water Infiltration (m^3)	Hydraulic conductivity (m/s)
	Top soil	Sub soil	(× 10^{-4})	(× 10^{-4})
Min	0.16	0.20	0.11	1.2
Max	0.31	0.35	2.3	3.8
Mean	0.21	0.28	1.52	2.57
Std.Dev	0.04	0.04	0.39	0.79
CV	14.95	31.27	35.90	51.90
Kurtosis	3.62	1.75	3.41	3.56
Skewness	1.11	0.15	1.27	1.25

The effect of soil texture, SOM and BD on SWC was deemed uniform because they were uniform across the sampling area (Table 7). In this sandy clay loam soil, an increase in SOM increased the SWC. According to Hudson, (1994); Saxton and Rawls, (2006), the result was in agreement with previous studies that observed that an increase in SOM increased SWC within the available water holding capacity and type of soil texture. The low bulk density is suitable for many agricultural crops, since a slightly high bulk density is not good for plant growth. Since, infiltration, aeration and root development are likely to be below optimum (Logsdon and Karlen,2004; Chaudhari et al., 2013). It is studied that soils with low bulk densities have favourable physical conditions (Chaudhari et al., 2012).

Table 7. The soil texture, bulk density and organic matter at the Roodeplaat Agricultural Research Council Experimental farm.

Grid	Soil texture class		Bulk density, ×10^3 (kg/m^3)		Soil organic carbon, (%)	
	Top soil	Sub soil	Top soil	Sub soil	Top soil	Sub soil
1	Sandy clay loam		1.13	1.24	0.52	0.51
2			1.01	1.13	0.98	0.49
3			1.21	1.32	0.56	0.26
4			0.98	1.01	0.90	0.55
5			1.05	1.12	0.86	0.23
6			1.23	1.37	0.72	0.66
7			1.17	1.34	0.49	0.39
8			1.21	1.35	0.83	0.46
9			1.05	1.21	0.40	0.35
10			1.15	1.29	0.92	0.40
11			0.94	1.07	0.59	0.27
12			0.89	1.02	0.74	0.66

Table 8. Descriptive statistics for bulk density and soil organic matter at Roodeplaat Agricultural Research Council Experimental farm.

	Bulk Density ×10^3 kg/m^3		Soil organic carbon (%)	
	Top soil	Sub soil	Top soil	Sub soil
Min	1.19	1.25	0.40	0.23
Max	1.62	1.71	0.97	0.66
Mean	1.40	1.51	0.70	0.43
Std.Dev	0.13	0.14	0.19	0.14
CV	10.54	10.94	32.76	59.96
Kurtosis	1.96	2.31	1.61	1.96
Skewness	1.49	0.52	0.13	0.19

4.3 Spatial variability of the soil hydro-physical properties at the University of Venda Experimental farm.

4.3.1 Spatial variability of soil water content at the University of Venda Experimental farm.

Most SWC was in the range 27.92 – 29.21% (Figure 4) in the top- compared to 40.53 – 45.11% (Figure 5) in the sub soil. The semi variograms of the soil water status parameters in the top- and sub soil is shown in Figure 6 and 7 respectively. The parameters showed moderate spatial dependence and the semi variograms were stationary lines implying spatial homogeneity. Homogeneous soil properties are better explained by the intrinsic variabilities (Cambardella et al., 1994). The soil texture in the area of study was similar throughout the sampled area (Table 3). Likewise, the BD was similar in the sampled area. Therefore, the low spatial variability of the two intrinsic soil properties caused the low spatial variability of the SWC.

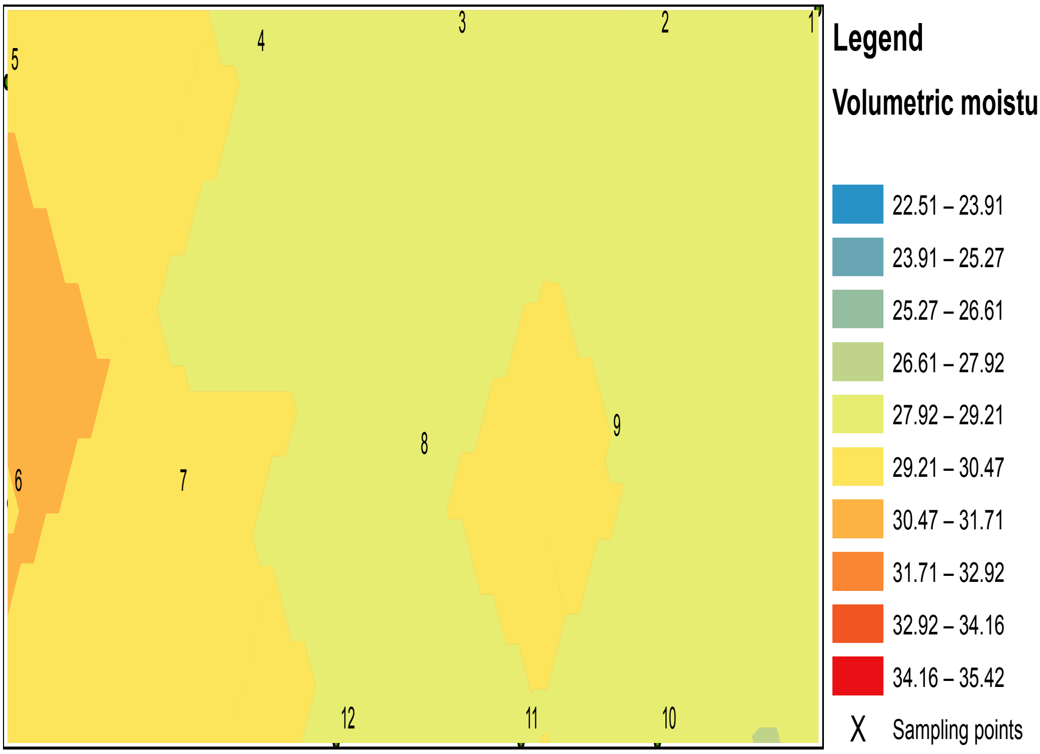

Figure 4. Spatial variability map of soil water content top soil at the University of Venda Experimental farm

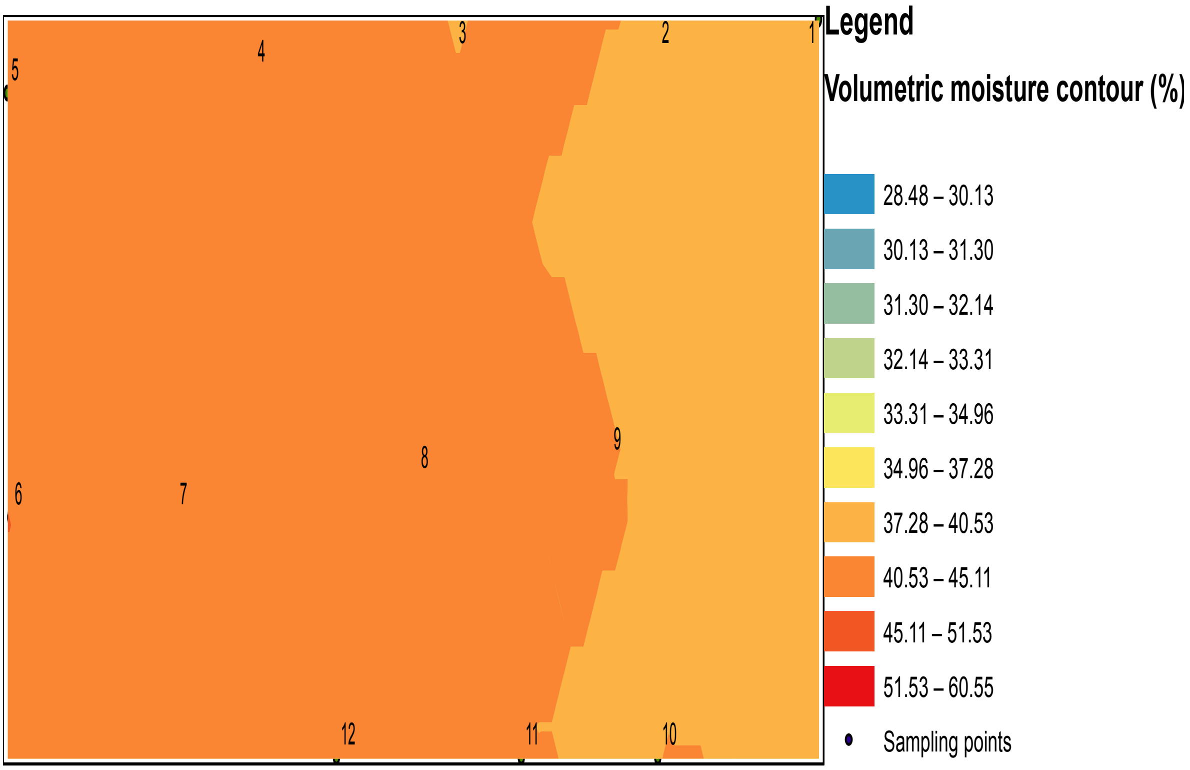

Figure 5. Spatial variability map of soil water content sub soil at the University of Venda Experimental farm.

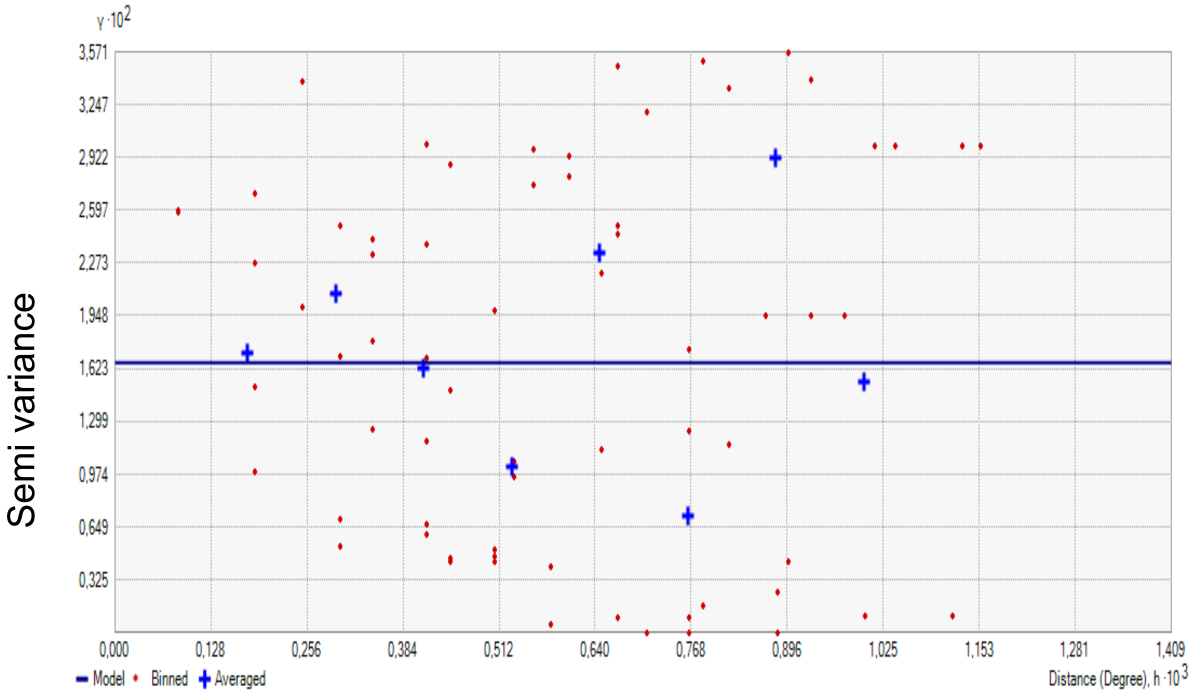

Figure 6. Semi variogram for soil water content in the top soil at the University of Venda Experimental farm

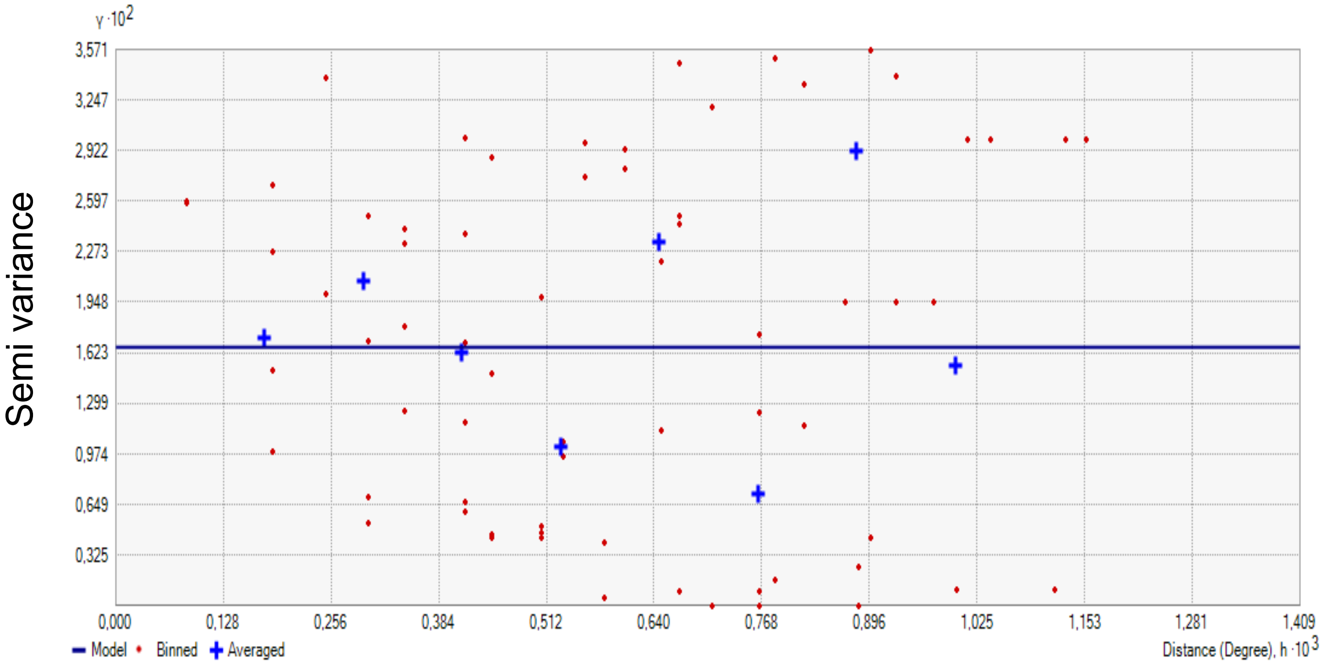

Figure 7. Semi variogram for soil water content in the sub soil at the University of Venda Experimental farm

4.3.2 Spatial variability of water infiltration at the University of Venda Experimental farm.

The University of Venda experimental farm found to have high value of infiltration rate and these results, however, could be related to the ferralsol features. Since ferralsols reported to display higher infiltration rate, as they contain macropores which makes easy for them to absorb enough water in the soil profile. Moreover, the water movement in these soils is quick and is observed on infiltration process through the use of mini disk infiltrometer (Ruiz and Utset, 1998). There was little spatial variability of the water infiltration at the University of Venda Experimental farm, this could probably be of textural classes not showing difference in depth (Figure 8).

The semi variogram is shown in Figure 9 and is a stationary line implying spatial homogeneity. According to Lennart et al. (2009) water infiltration, spatial variability is strongly influenced by BD because of reduced soil porosity that restrict water movement. In this study, BD was similar in all sampling points. Therefore, BD exerted uniform influence on water infiltration thereby causing little spatial variability in water infiltration.

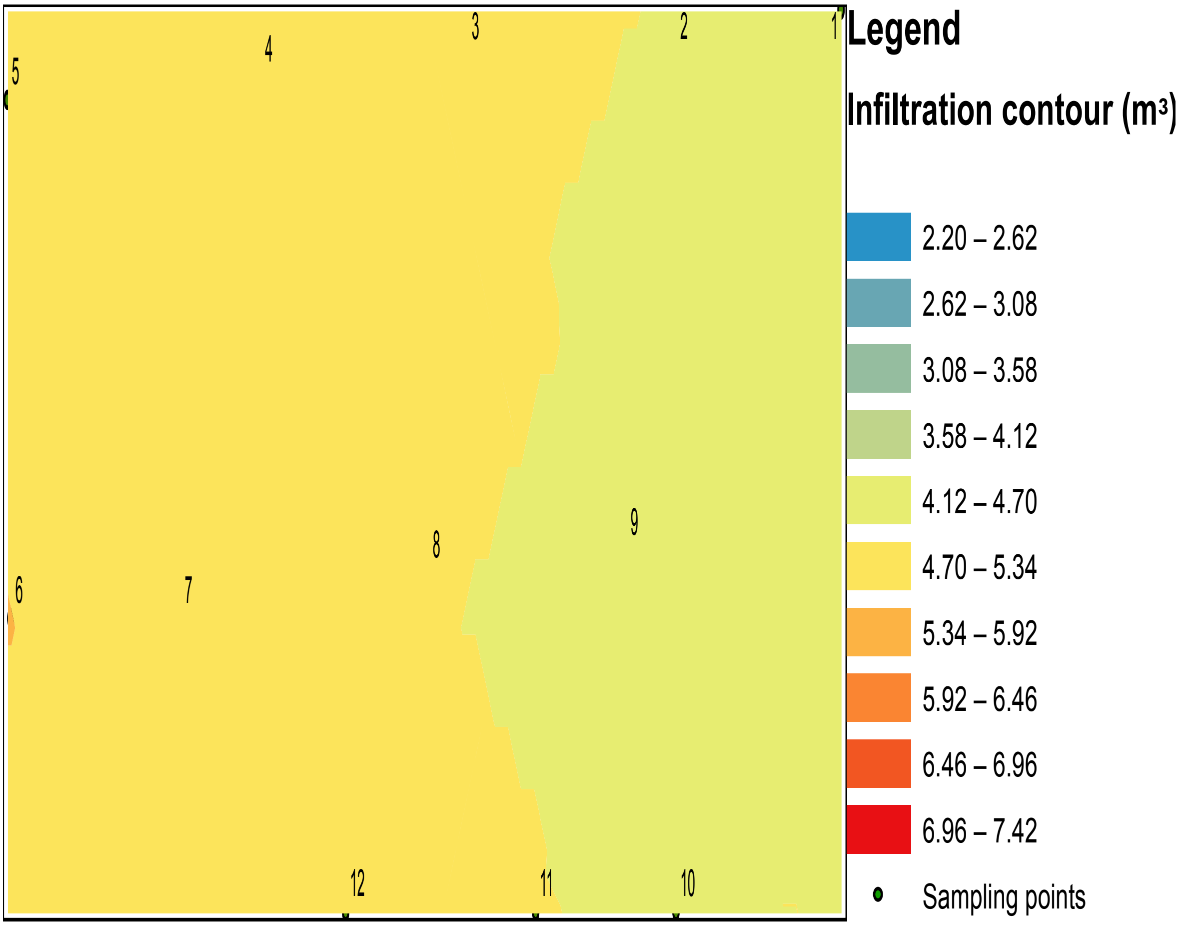

Figure 8. Spatial variability map of the water infiltration at the University of Venda Experimental farm

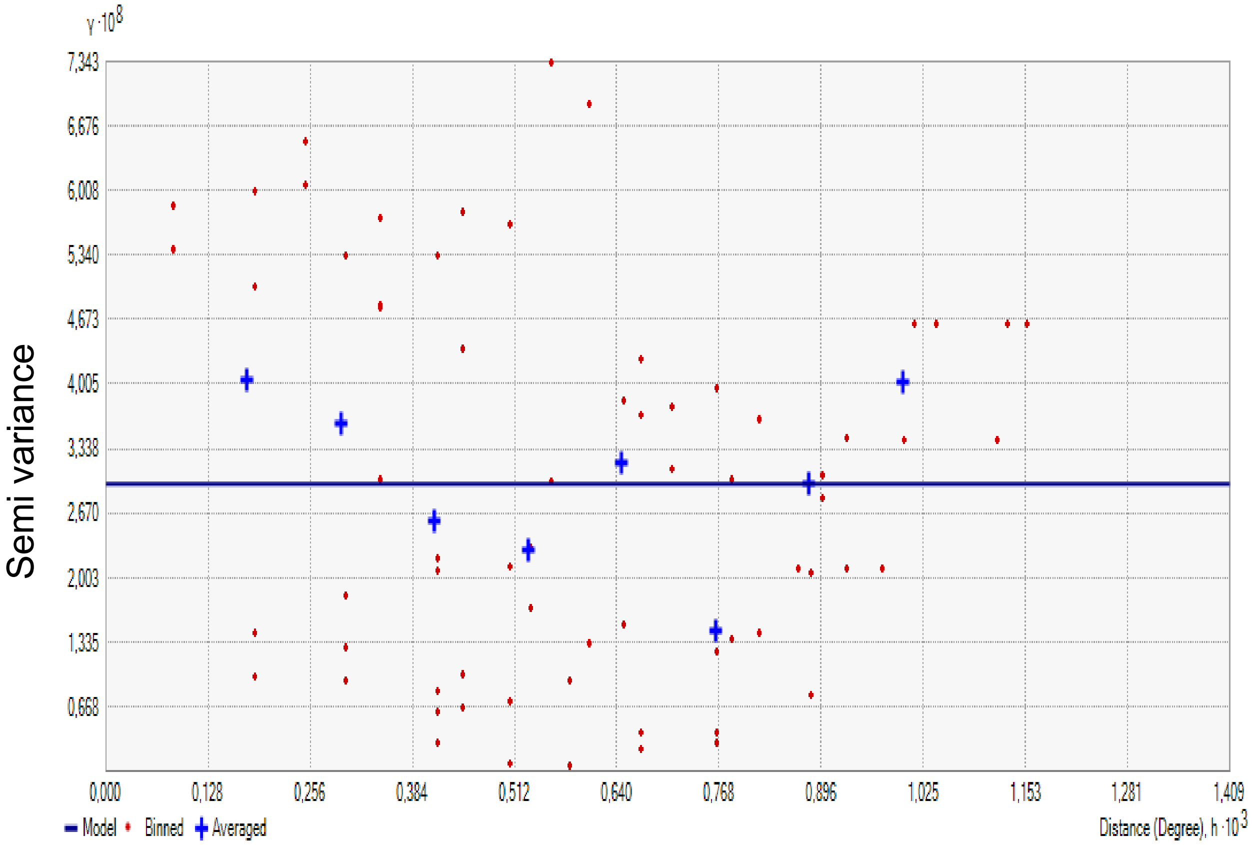

Figure 9. Semi variogram for water infiltration at the University of Venda Experimental farm

4.3.3 Spatial variability of hydraulic conductivity at the University of Venda Experimental farm

The soil hydraulic conductivity had a near constant semi variograms as shown in Figure 10 and 11. According to Logsdon and Jaynes (1996), the hydraulic conductivity depends strongly on porosity. Porosity was not measured in this study but can be inferred from the constant BD. Since BD showed insignificant spatial variation in the sampled area (Table 4), then, porosity had a similar effect on hydraulic conductivity. The University of Venda experimental farm have high value of hydraulic conductivity and these results, however, could be related to the ferralsol features. Since, ferralsols are reported to display higher hydraulic conductivity values, as they contain macropores which make it easy for them to absorb enough water in the soil profile similar to sandy soils (Mzezewa and Van Rensburg, 2011).

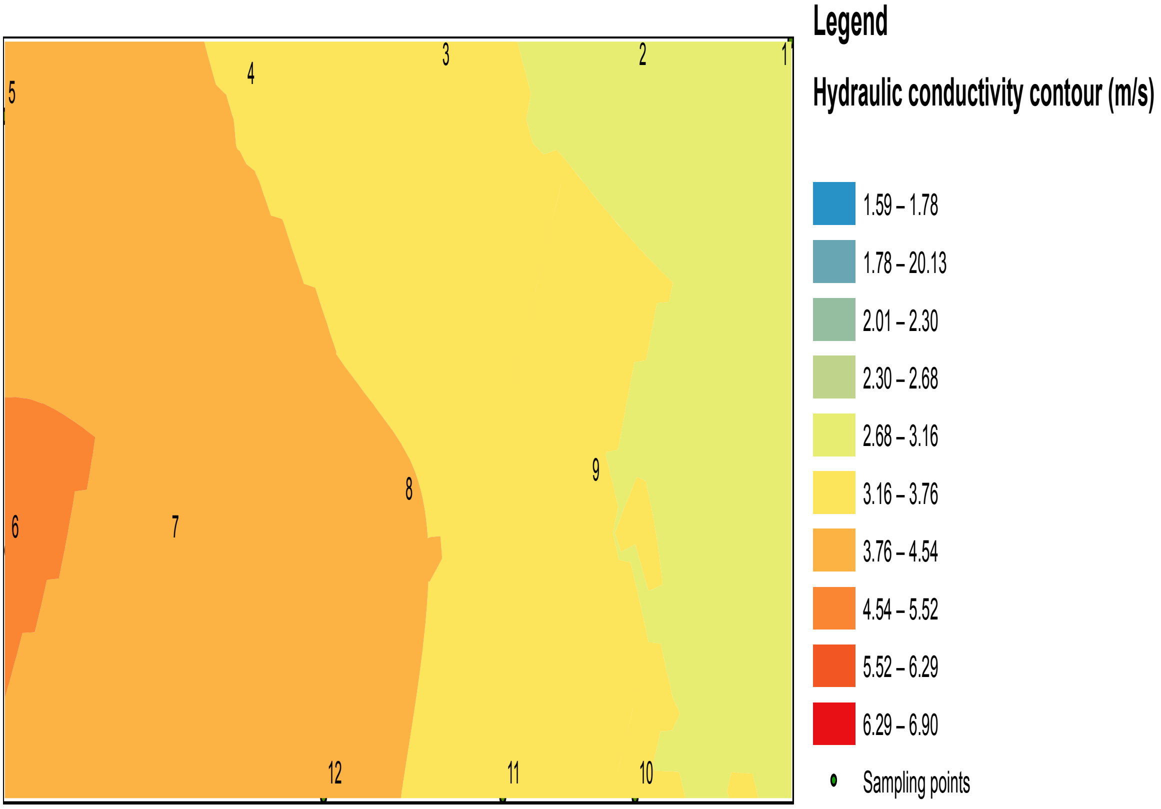

Figure 10. Spatial variability map of the hydraulic conductivity top soil at the University of Venda Experimental farm

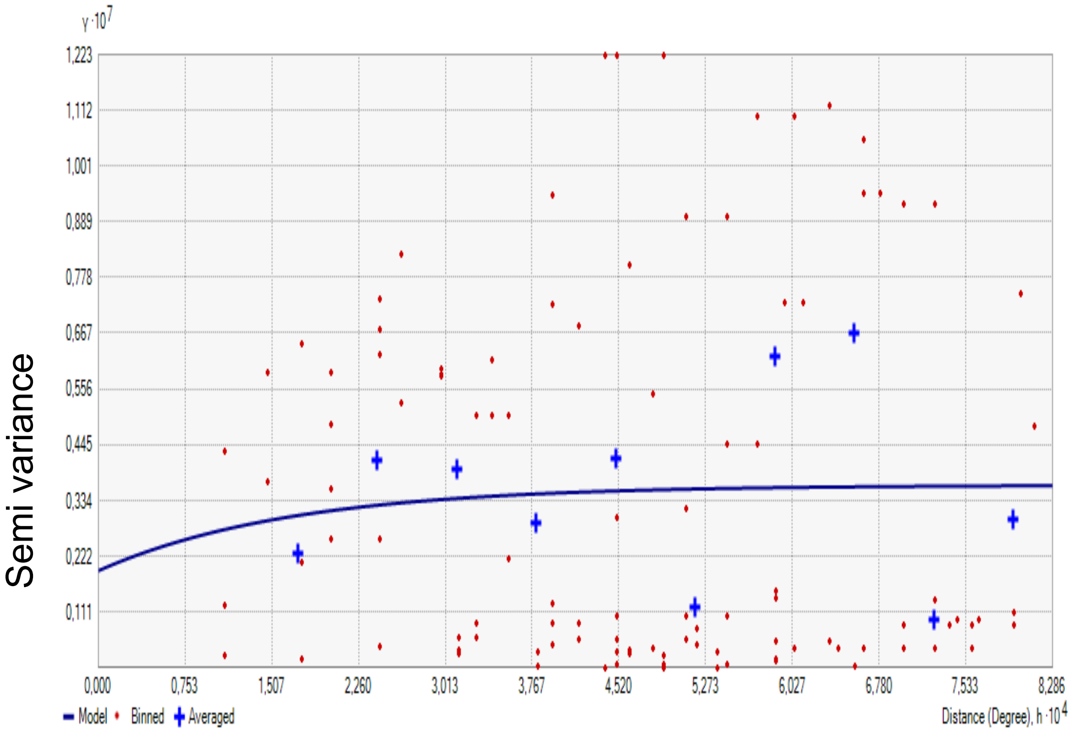

Figure 11. Semi variogram for hydraulic conductivity in the top soil at the University of Venda Experimental farm

4.4 Spatial variability of the soil hydro-physical properties at the Roodeplaat Agricultural Research Council Experimental farm

4.4.1 Spatial variability of soil water content at the Roodeplaat Agricultural Research Council Experimental farm

Water content was spatially variable across the sampling area (Figures 12 and 13). Therefore, both extrinsic factors such as tillage and inherent soil properties such as texture and BD (Cambardella et al., 1994) could have influenced the spatial variability of soil water content. The semi variograms are shown in Figure 14 and 15. Tillage was done using a mouldboard plough and disc harrow, which could have contributed to the observed spatial variability. Tillage creates microenvironments on the soil surface. It also means that sandy clay loam texture caused highly variable effect on soil water content after tillage.

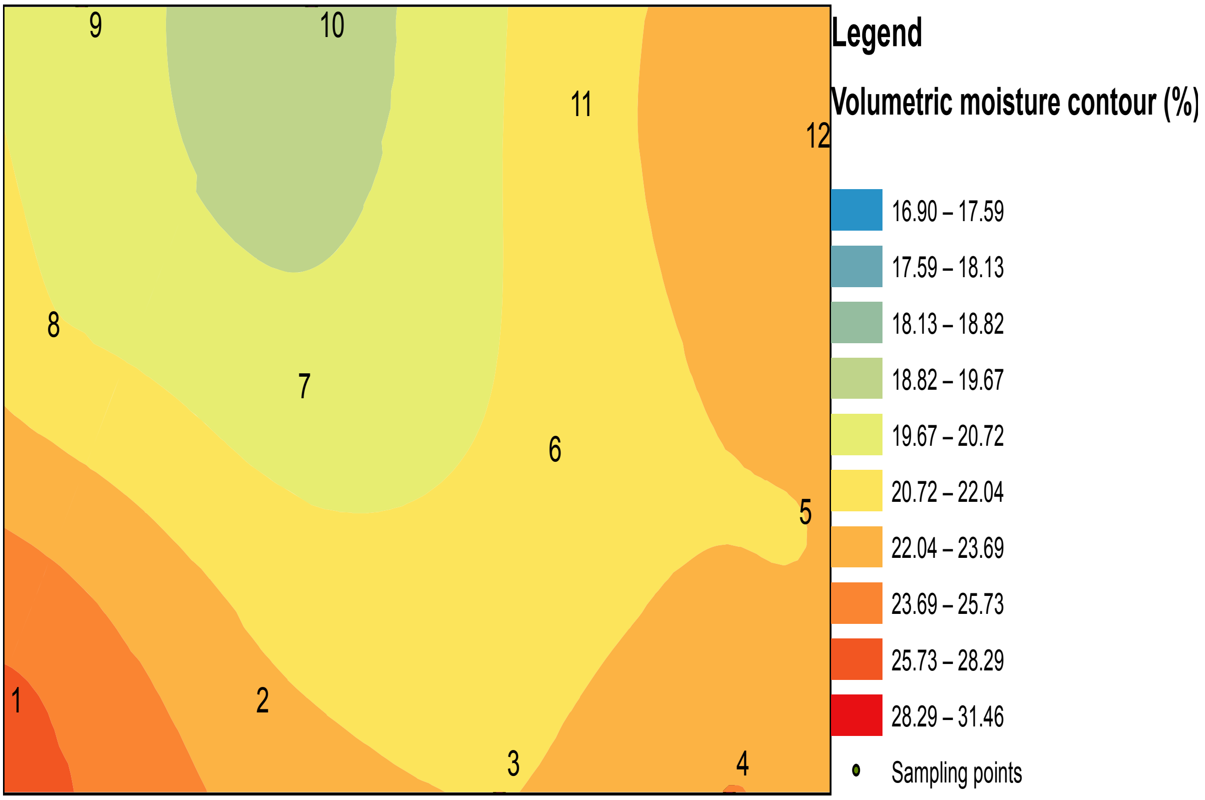

Figure 12. Spatial variability map of the soil water content in the top soil at the Roodeplaat Agricultural Research Council Experimental farm

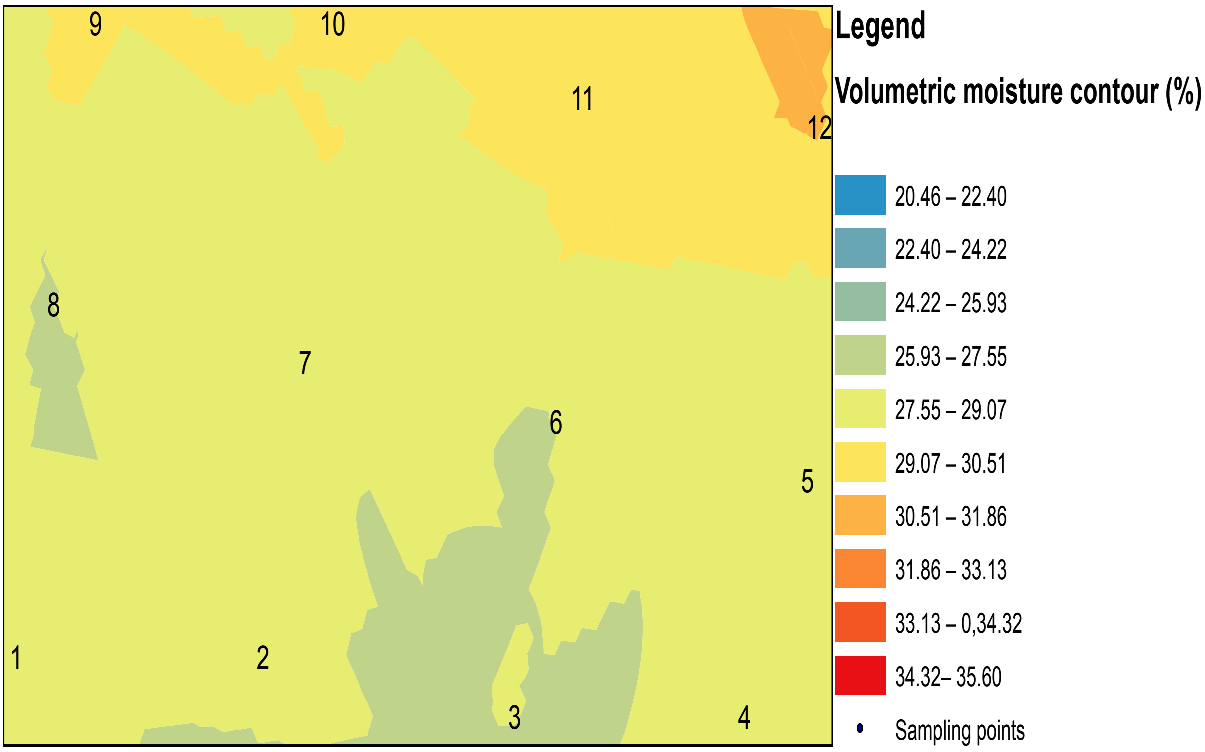

Figure 13. Spatial variability map of the soil water content in the sub soil at the Roodeplaat Agricultural Research Council Experimental farm

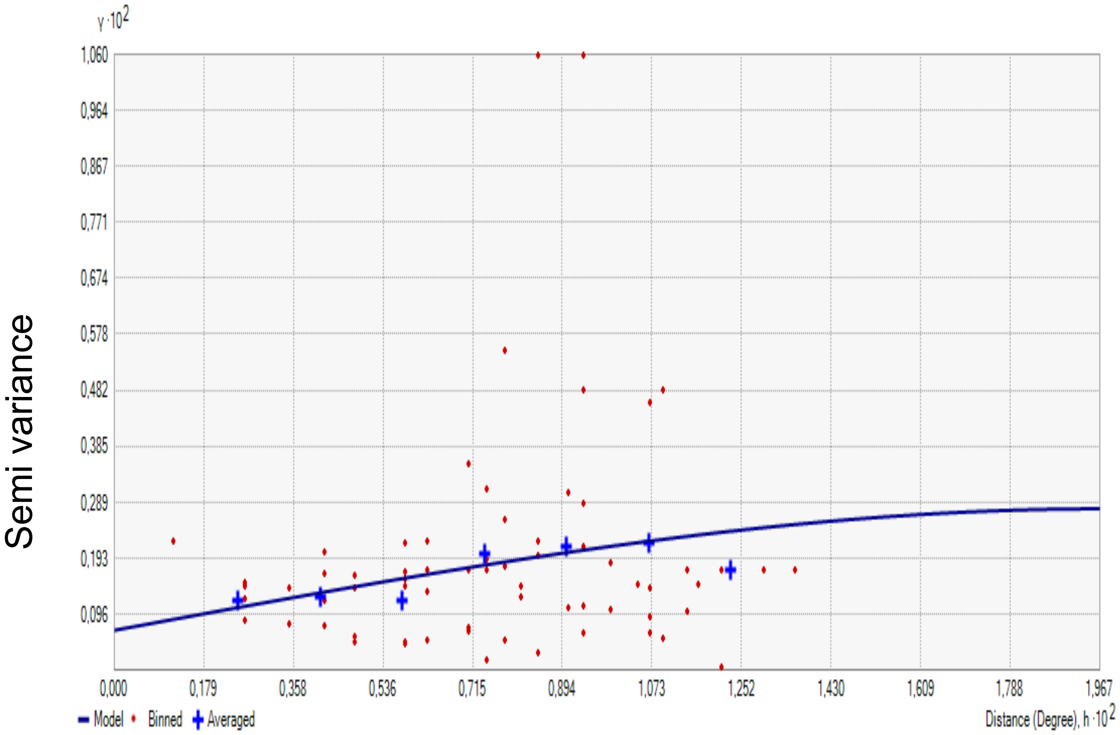

Figure 14. Semi variogram for soil water content in the top soil at the Roodeplaat Agricultural Research Experimental Council farm

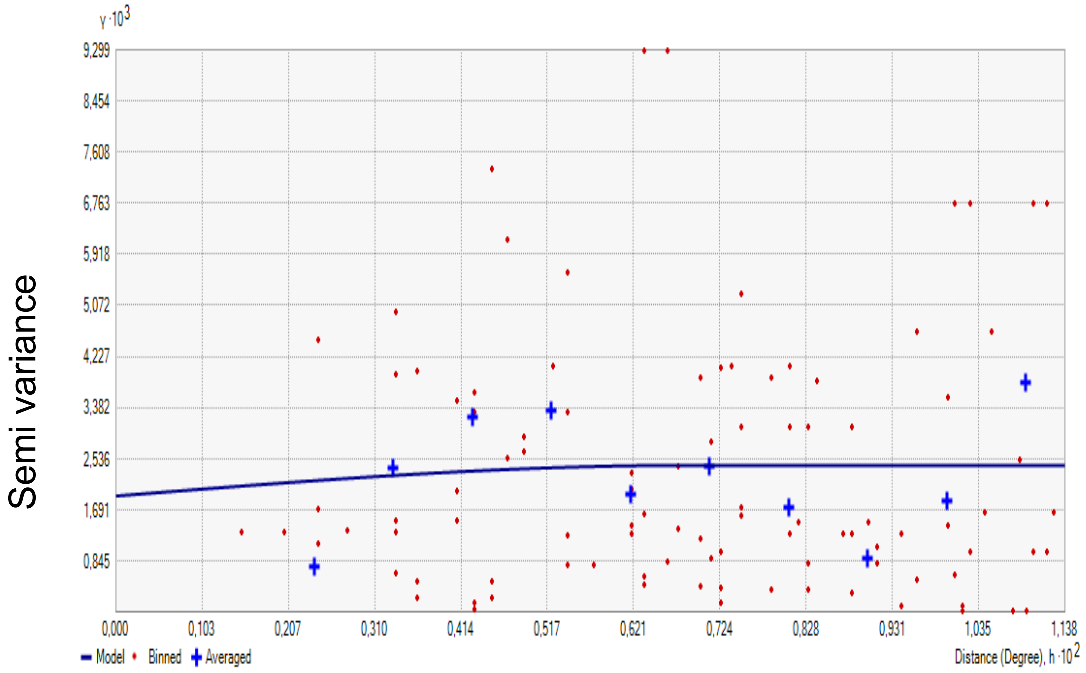

Figure 15. Semi variogram for soil water content in the sub soil at the Roodeplaat Agricultural Research Council Experimental farm

4.4.2 Spatial variability of water infiltration at the Roodeplaat Agricultural Research Council Experimental farm

The water infiltration contour map shown in Figure 16 displays huge spatial variability. Relative to water content, water infiltration was affected more by the tillage of the sand clay loam soil (Figure 16). ARC-Roodeplaat soil have high variability for both cumulative water infiltration and hydraulic conductivity. Variation was observed when the soil absorbs and infiltrates water differently on the same piece of land. Moreover, the hydraulic conductivity depends on the available porosity that allows the percolation of water to channel to the soil profile. The contour maps reveal high variability at ARC-VOPI grid points for both water infiltration and hydraulic conductivity.

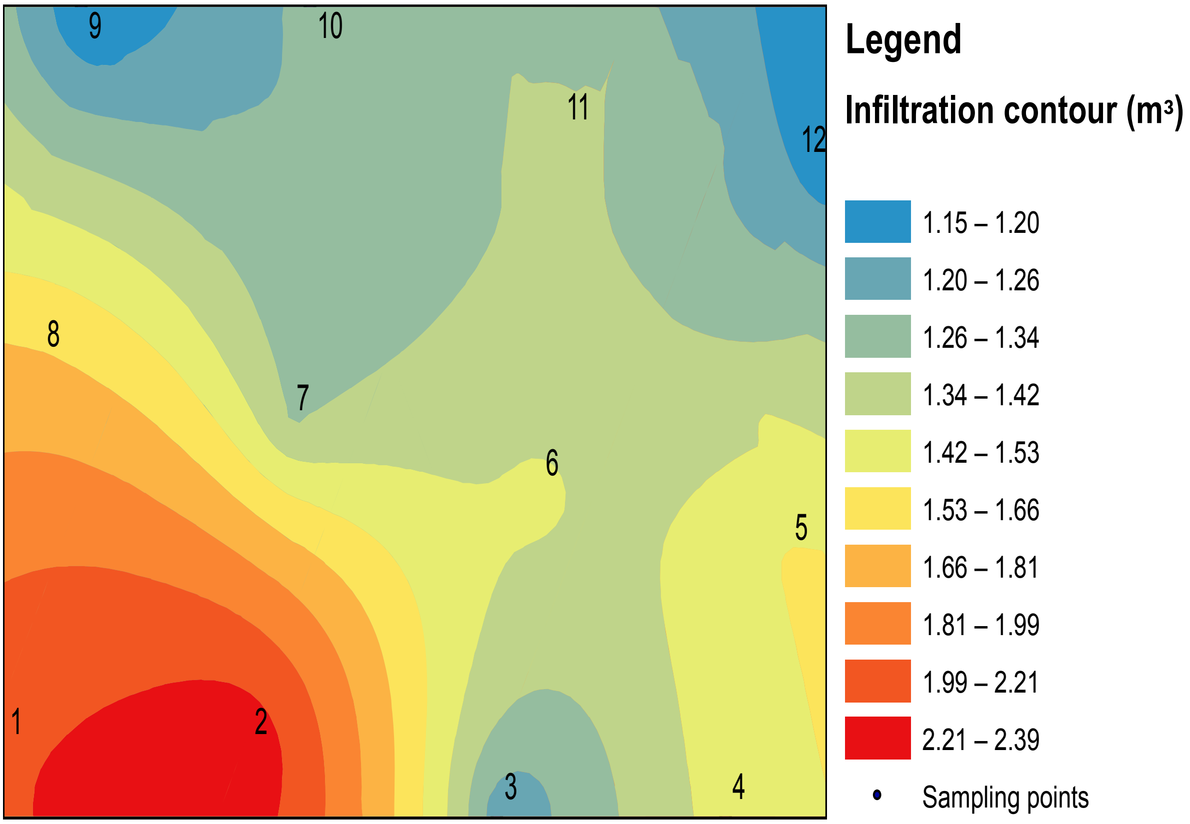

Figure 16. Spatial variability map of the water infiltration at the Roodeplaat Agricultural Research Council Experimental farm.

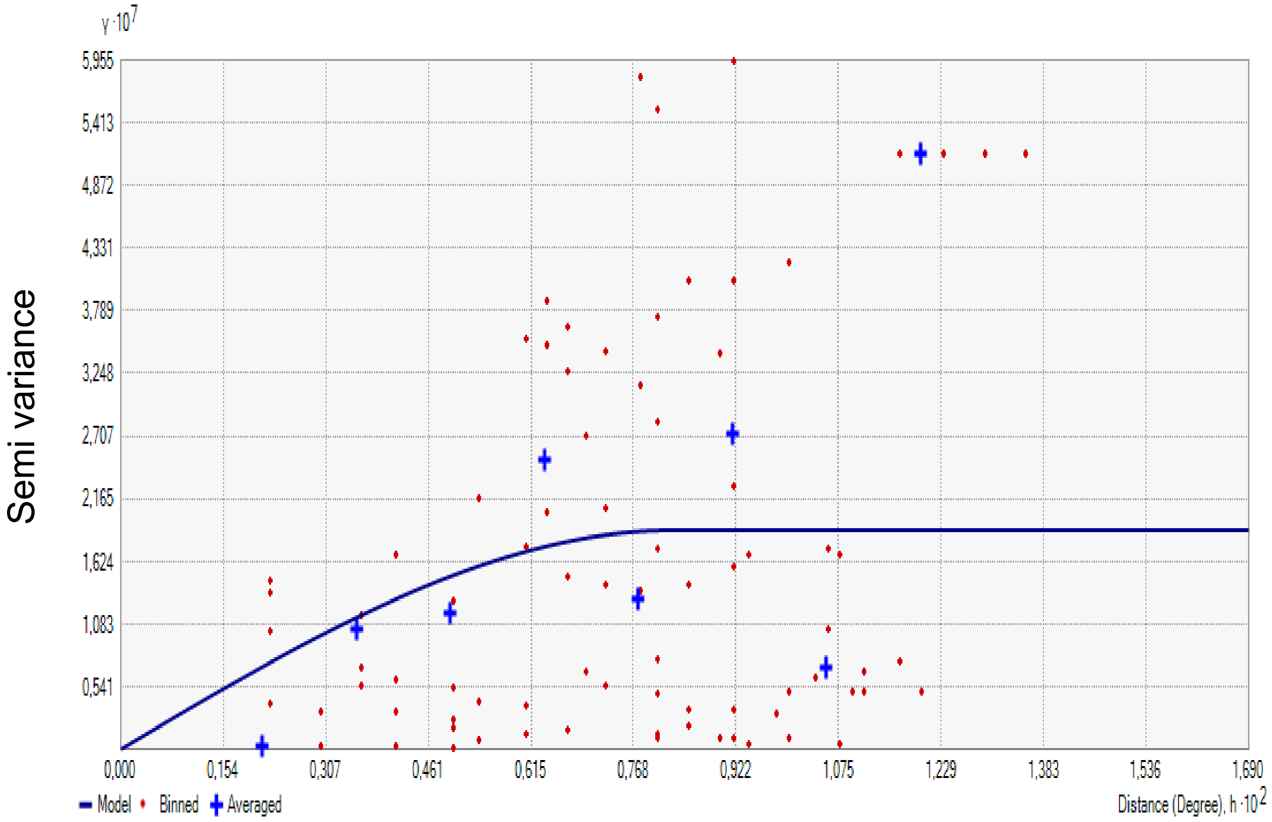

Figure 17. Semi variogram for water infiltration at the Roodeplaat Agricultural Research Council Experimental farm

4.4.3 Spatial variability of hydraulic conductivity at the Roodeplaat Agricultural Research Council Experimental farm

Figure 18 and 19 show the spatial variability map and semivariogram of the hydraulic conductivity at the Roodeplaat Agricultural Research Council Experimental farm in both top- and sub soil. Hydraulic conductivity displayed high spatial variability and appeared to follow a gradient (Figure 18). According to Rawls et al. (1998) hydraulic conductivity depends on the available porosity and channel through the soil profile. Since porosity was not directly measured in this study, its effects on hydraulic conductivity can be inferred from the soil texture and BD. Since BD showed insignificant spatial variation in the sampled area (Table 4), then, porosity had a similar effect on hydraulic conductivity. So the effect of sandy clay loam texture after tillage seem to be dominant.

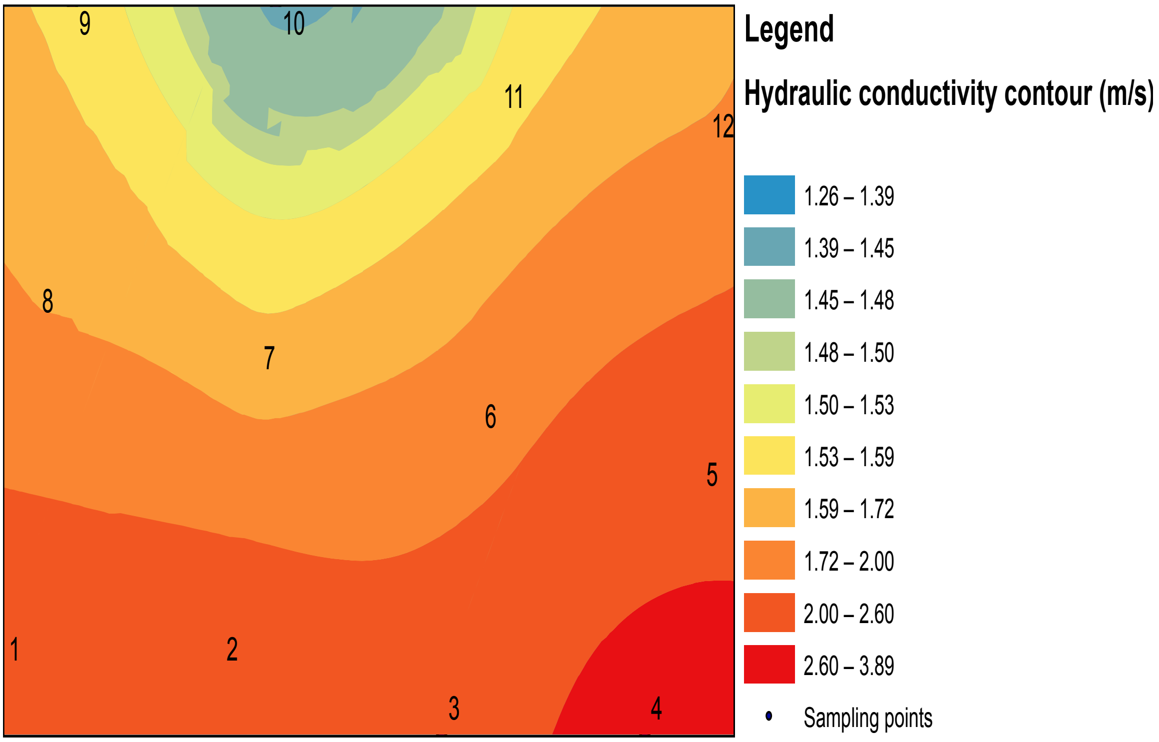

Figure 18. Spatial variability map of the hydraulic conductivity top soil at the Roodeplaat Agricultural Research Council Experimental farm.

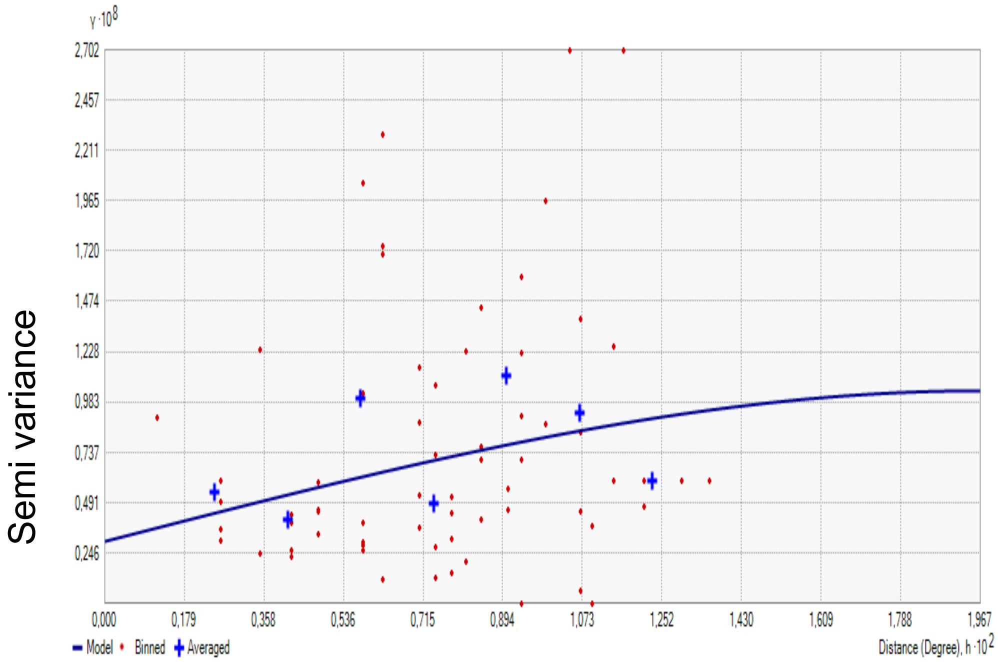

Figure 19. Semi variogram for hydraulic conductivity at the Roodeplaat Agricultural Research Council Experimental farm.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

Finer soil texture under tillage did not affect the spatial variability of the soil hydro-physical properties. The spatial variability of soil water status at University of Venda Experimental farm was very low confirmed by contour maps depicting slightly homogeneity. The soil properties on contour maps were closely related to each other and this may be initiated through field being undisturbed for a long period. The empirical variograms of spherical model fits were assuming strong spatial dependence with a straight-line variogram.

Coarse soil texture under tillage caused greater spatial variability of the soil hydro-physical properties at Roodeplaat ARC experimental farm. The effect of bulk density and soil organic matter also showed the spatial variability in the field. The greater variability of soil water status properties may be induced by tillage of the coarse texture soil.

The produced spatial variability maps can be used as an effective tool to implement site-specific crop management and land use planning. It is recommended that further studies be done on the effect of coarse soil texture on the spatial variability of soil hydro-physical properties under different tillage systems.

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