Conservation agriculture and slope position effect on selected soil physical properties of a Vertisol at Tshivhilwi in Limpopo Province

By

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A research dissertation for Master of Science in Agriculture (MSCSSC) Degree

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2022

Declaration

I, **Mushe Moses Tshilonga (11640720)**, hereby declare that this dissertation titled ‘**Conservation agriculture and slope position effect on selected soil physical properties of a Vertisol at Tshivhilwi, Limpopo Province’** for degree of Master of Science in Agriculture submitted to the department of Plant and Soil Science, Faculty of Science, Engineering and Agriculture, University of Venda has not been submitted previously for any degree at this or another University. It is original in design and in execution and all reference material has been acknowledged.

Signature: Date: 27/02/2023

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Acknowledgment

I'd like to express my gratitude to "God" for making everything possible for me by providing me with courage, dedication, and wisdom since the beginning of my studies. I acknowledge the department of agriculture, land reform and rural development, for the financial support. I'd also like to express my gratitude to Dr. J Mzezewa, my supervisor, for leading, supporting, and encouraging me during this research. Dr, I appreciate your patience. I'd also like to express my gratitude to Prof. J.J.O. Odhiambo, my co-supervisor, for his invaluable contributions to this research. Thank you for your valuable contribution to the completion of this research. Mr Makhale for making it possible for me to use his land to conduct my research study, you are appreciated. It gives me great pleasure to thank my MSc Agriculture students at the University of Venda for their continued assistance. Finally, I'd want to express my gratitude to the University and Mutanga wa Ndodzi Agriculture Co-operative for providing all the resources needed to conduct the research.

Dedication

I would like to dedicate this dissertation to myself and my family. Especially for the support they showed me during this journey.

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List of abbreviation

Acronym	**Description**
AS	Aggregate stability
BD	Bulk density
CA	Conservation agriculture
CI	Cumulative infiltration
CIMMYT	International maize and wheat improvement centre
CT	Conventional tillage
EC	Electrical conductivity
IR	Final infiltration rate
LS	Lower slope
LSD	least of significant difference
MS	Middle slope
NG	Natural grassland
NTSC	No-tillage with straw cover
PAWC	Plant available water capacity
Pd	soil particle density
S	Summit
SOC	Soil organic carbon

SOM	Soil organic matter
TTSR	Traditional tillage with straw cover
Vf	soil total porosity
WHC	Water holding capacity

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Abstract

Conservation agriculture (CA) is a production system that involves three principles which are minimal or zero tillage, crop rotation and mulching with plant residues. CA improves soil physical properties resulting in soil fertility improvement. However, there are relatively few studies that have documented the benefits of CA on soil physical properties of vertisols.

A study was conducted to determine the influence of CA and slope position on soil bulk density (BD), total soil porosity (Vf), soil aggregate stability (AS), soil water holding capacity (WHC), soil organic carbon (SOC), soil electrical conductivity (EC), infiltration rate (IR) and cumulative infiltration (CI) of a vertisol, at Mutanga Wa Ndodzi Agricultural Co-operative at Tshivhilwi village where CA has been in practice since 2013. The farm practices CA with crop rotation. The field used for CA was tilled once in 2013 using a mouldboard plough. Mulching is done using maize stalks. After planting fertilizer was applied based on crop requirement. One set of soil samples were collected from a field under CA while another set was collected from a field under natural grass (control) which is located directly opposite the CA field. Soil samples were collected 10 m apart from 0-10 and 10-20 cm depths along the transects which were at, 10 m apart. A core of diameter of 5 cm and height of 5 cm was collected to determine soil BD. SOC was determined using the modified Walkley-Black wet oxidation procedure. EC was measured with glass electrode professional EC meter in 1:5 ratio soil water suspension. Soil AS was determined using wet sieving method. Soil particle density was determined using a pycnometer bottle after which the bulk density and particle density of the soil were used to calculate soil porosity. Soil WHC was determined by saturating with water 25 g of oven-dried soil in a glass funnel and its water holding capacity determined by gravimetric method.

Management and slope position interaction had a significant effect at 0-10 cm and 10-20 cm soil depth with lower BD at the CA site lower slope position at 0-10 cm soil depth. SOC was significantly higher on lower and middle slope of CA than natural grassland (NG) site. The CA site recorded higher EC at the middle and lower slope positions compared to NG site. Higher AS was observed at the CA site than NG at all slope position at 0-10 cm soil depth, at 10-20 cm CA site recorded higher AS at the lower and middle slope. Vf was significantly higher at the CA site than NG site at all slope positions, CA lower slope was associated with higher Vf followed by middle and summit slope. CA site exhibited a higher WHC than NG site at all slope positions, CA middle lower slope positions had the highest WHC. Interaction effect was observed on final IR however, the significant difference between the two-management system was observed at lower and middle slope. Conservation agriculture and slope position interaction in this research resulted in significantly higher BD, SOC, EC, AS, vf and WHC but had no effect on BD middle slope and summit slope positions at 0-10 cm, SOC summit and lower slope positions at 10-20 cm soil depth, EC summit slope at 0-10 cm, vf at summit and middle slope at 10-20 cm soil depth and WHC lower slope lower slope position at 10-20 cm soil depth. According to the findings of this study, practicing conservation agriculture in various slope positions could be recommended to improve soil properties (bulk density, soil organic carbon, soil electrical conductivity, aggregate stability, total soil porosity, water holding capacity and infiltration rate) of a Vertisol.

Key word: Conservation agriculture, Physical properties, Slope position, Vertisol,

Chapter 1

1.1 Introduction

Conservation Agriculture (CA) is an agriculture production system that involves minimal or zero tillage and crop rotation. In addition, CA entails covering the soil surface with crop residues. Conservation agriculture is a sustainable production system in terms of money as it costs less to the farmer to produce (FAO, 2019). Conservation Agriculture sustains resources such as water because one of CA's benefits is to improve infiltration and water holding capacity of the soil (FAO, 2019). As highlighted in the following paragraphs, numerous studies have documented the benefits of CA.

CA increases water infiltration and decreases soil water evaporation thereby increasing rainfall use efficiency. It also decreases runoff and soil erosion (Thierfielder et al., 2017). Furthermore, Musukwa (2017) reported that CA improves other soil physical properties leading to good soil fertility. For example, the building up of Soil Organic Matter (SOM) through Conservation Agriculture improves soil structure and increases soil moisture holding capacity (Giller et al., 2009). In addition, soil bulk density is reduced due to minimal soil disturbance and high amount of organic carbon (Kuman et al., 2018). CA increases soil aggregate stability in both high clay and low clay soils compared with Conventional Agriculture (Giller et al., 2009). Nevertheless, CA's effect is influenced by a slope position.

Slope positions affect the quality of soil physical properties due to factors such as erosion and underground water movement (Plaster, 2013). Therefore, it is important to consider slope position when planning soil management practice. Usually, lower slope positions contain a high amount of soil organic carbon and have good aggregate stability compared to other slope position due to the deposition of materials from another slope positions (Pierson, 1990). Physical properties of soil such as bulk density and porosity are also affected by slope. It is generally agreed that slope position has great impact (Kuman et al., 2018). However, information on how CA affects vertisol properties is not readily available in literature. More so, little is reported on slope position effects on vertisols under CA practice.

Vertisols are dark clayey soils which have strong shrink-swell mineralogy and usually develop under different climates- including tropical and subtropical zones (Rezaei et al., 2015). They are important in plant production due to their high nutrient content, good soil physical properties and their high clay content. However, due to intensive agricultural cultivation, vertisols often lose their soil properties, such as SOM, porosity and soil structure resulting in lower productivity (Zhang et al.,2015).

Water on the ground surface infiltrates the soil through the process of infiltration. Infiltration is critical for soil and water conservation because it determines the amount of runoff over the soil surface during irrigation and precipitation. The infiltration rate of a soil, and consequently its ability to withstand excessive rainfall or irrigation, is determined by the soil's physical properties (Oku et al., 2011). Vertisols may present infiltration problems especially under conditions of high sodium content which causes deflocculating of soil colloids and subsequent collapse of soil structure. Moreover, infiltration in vertisol is difficult to measure due to its shrinking-swell properties (Oku et al., 2011). Currently there is paucity of knowledge on how CA influences vertisol infiltration properties.

1.2 Problem statement

Conventional tillage is a common practice whereby soil is turned over and crop residues removed from the field. This leaves the soil bare - loosens soil particles and exposes the soil to the erosive force of wind and water. Soil disturbance through conventional tillage is a cause of land degradation through soil structure destruction and organic matter depletion. In contrast, Conservation Agriculture (CA) is known to arrest land degradation and improves soil productivity. While there is a drive towards practicing CA in South Africa, its impact on physical properties of

Vertisols is not well understood, particularly those properties known to influence crop production such as the soil's water holding capacity and water transmission need further investigation. These properties influence crop water availability, which is responsible for increased crop yields. Understanding soil physical properties is critical for defining and/or improving soil water management practices to achieve optimal productivity for each soil condition. While the distribution of soil properties across a topo-drainage sequence in the tropics is predictable, there is dearth of knowledge on how CA activities influences the distribution soil properties across different slope positions. Therefore, this study attempts to fill this knowledge gap. The aim of this study is to evaluate the effect of Conservation Agriculture on some physical properties of a Vertisol across different slope positions. An adjacent natural grassland is used as the control.

1.3 Significance of the study

Practicing CA is a sustainable way of soil management which in addition to bringing cost savings for the farmer by means of minimal soil disturbance which also aids in soil organic matter that builds up through mulching. Benefits of increasing soil organic matter results in improved soil structure that lead to reduced soil erosion, low bulk density and increased water infiltration. Furthermore, CA provides plant nutrients through organic matter decomposition thereby saving the farmer the cost of inorganic fertilisers. Improved soil properties lead to increased crop yields and household food security.

Findings from this research generates knowledge on how Vertisols respond to CA practice across different slope positions and may guide agriculture experts in developing recommendations for the adoption of CA on vertisols.

Objectives

1.4.1 Main objective

To determine the effect of Conservation Agriculture and slope position on selected soil physical properties of a Vertisol in Limpopo Province.

1.4.2 Specific objective

To determine the effect of CA and slope position on:

a. Soil bulk density
b. Soil organic carbon
c. Soil electrical conductivity
d. Soil aggregate stability
e. Soil total porosity
f. Water holding capacity

1.4.3 Null hypotheses (H_O)

Conservation Agriculture and slope position does not have a significant effect on soil:

a. Bulk density
b. Soil organic carbon
c. Electrical conductivity
d. Aggregate stability
e. Total porosity
f. Water holding capacity

Chapter 2

Literature review

2.1 Conservation Agriculture

Conservation Agriculture (CA) is a type of crop production system that ensures minimal physical disturbance of soil through zero or minimum tillage. It provided permanent soil cover which was accomplished either through growing a crop or mulching with dead crop residues. In addition, crop rotation and intercropping are an integral part of CA (Giller et al., 2017). Conservation Agriculture was at its infancy in South Africa yet in the early 1950's, when the USA started to practice Conservation Agriculture and it was one of the countries that had the largest hectarage under Conservation Agriculture (Kassam, 2020). Conventional tillage resulted in soil erosion because the soil was unprotected (Chivenge et al., 2007). Conservation Agriculture was introduced to reduce soil degradation and increase soil fertility. More small- scale and large-scale farmers adopted this agricultural practice system over the world (Kassam et al., 2017).

Appropriate CA inputs (e.g., organic manure, compost, and other better management practices) were critical to the success of CA in deficient soils, as they resulted in greater productivity. Given the wide range of CA benefits elsewhere in the world, it was vital to look into the viability and potential of CA to alleviate food security restrictions in South Africa in a variety of environmental conditions (Nyamangara et al., 2015).

2.2 Conservation Agriculture (CA) in South Africa

The productivity of rainfed cropping systems in South Africa is well below capacity, largely due to poor soil fertility associated with prolonged dry spells in the mid-season (Nyamangara et al., 2015). The use of CA in the sub-region should therefore be assessed against its ability to reduce climate risk in the face of significant crop yield losses associated with soil moisture deficits. The initial version of CA in Southern Africa was first introduced at a commercial farm in the sub-humid area in the 1980s (Nyamangara et al., 2015). Most smallholder farmers who practiced CA in South Africa had mostly adopted minimum tillage.

In the 1980s, a commercial farm in the sub-humid area of Zambia was the first to adopt the first version of CA in southern Africa (Thierfelder et al., 2017). The goals back then were to prevent soil erosion, stabilize agricultural yields, and improve profits by reducing soil tillage and retaining crop residues (Nyamangara et al., 2015). CA's goal is more expansive, and it is founded on three principles: minimal soil disturbance, permanent soil cover given by mulch, and crop rotation (Thierfelder et al., 2017). CA was first widely promoted in Southern Africa few years ago, when the International Maize and Wheat Improvement Center (CIMMYT) was established. CA was mostly practiced by large commercial farmers in South Africa, and it was still in its early stages in most of the region in Zambia.

Agricultural productivity was generally low on many smallholder farms in Southern Africa because of declining soil fertility, inadequate and unsuitable fertilizer application, unpredictable rainfall and a changing climate, a lack of cultivars, labor shortages, and occasionally poor tillage practices (Thiefelder et al., 2015**)**. Thus, an increasing number of farmers were locked in abject poverty, food insecurity, and malnutrition (Ngwira et al., 2013). A cropping system based on no tillage, mulch cover made of living or dead plants, and diverse crop rotation and relationships have been proposed as a possible remedy to such restrictions in Southern Africa (Thiefelder et al., 2017).

Organic matter decomposition, soil moisture, rainfall infiltration, and soil erosion were all impacted by CA practices such as no-tillage, mulching with live or dead plants, and crop rotation. Higher moisture conservation during critical crop phases increased crop yields at harvest or reduced the risk of total crop failure in scenarios of unpredictable rainfall distribution marked by mid-season dry spells, where CA may make a difference. No-tillage with mulch and herbicide treatment appeared to sustain and boost soil production and increased maize yields in the tropics (Thiefelder et al., 2017).

South Africa's agricultural resources were limited, and much of the nation was considered marginal and vulnerable to environmental damage (Laker, 2004). In South Africa, SOM levels were naturally low, with 70% of soils containing less than 0.5 percent SOM (Swanepoel et al., 2016). Low SOM or an indicator of it Soil Organic Carbon (SOC) was frequently linked to poor soil structure, crusting, low water infiltration, and nutrient status whereas high SOM or SOC were indicative of healthy, productive soils (Swanepoel et al., 2016). Cultivation further degraded the already low SOC condition of South African soils (Swanepoel et al., 2016). In southern Africa, CA, a sustainable and regenerative agriculture technique that preserves or replenishes SOC and enhances soil health, has received more attention (Smith et al., 2016).

2.3 Vertisols

Vertisols are dark clayey soils with strong shrink-swell mineralogy (Rezaei et al., 2015). According to SSSA (1997) vertisols usually had deep wide cracks when dry and wedge-shaped structural aggregates. Vertisols develop under different climatic conditions. They are found in tropical and subtropical zones (Rezaei et al., 2015). They are also found in the cold temperature regimes (Rezaei et al., 2015). Most of Vertisols are dark in colour due to large variable organic matter content on the surface horizon.

Vertisols are important in crop production because they had high water holding capacity due to a high clay content and a deep soil profile (Virmani et al., 2000). Usually, the top layer of Vertisol consisted of a high percentage of organic matter which is rich in plant nutrients essential for plant growth. Due to heavy rains Vertisol became waterlogged and sticky and it is difficult for farmers to cultivate in such soil condition. However, CA decrease the level of water logging and stickiness because the soil is covered by crop residues as part of mulching (Pathak et al.,2011).

When properly managed, vertisols can be very productive due to their relatively high inherent fertility. However, their distinct physical properties are the most significant constraints to predominantly low-input agriculture. They necessitate careful management to realize their full potential while avoiding a decline in soil quality.

2.4 Effect of slope position on soil physical properties

One of the most important factors in universal soil loss is slope. Its geometry, such as slope angles and length, had a substantial impact on runoff, drainage, and soil erosion, with significant differences in soil physical attributes. As the slope length and steepness increase, as well as a corresponding rise in surface runoff velocity and volume, erosion was projected to occur.

Soil physical properties changed with slope position even when the soil is formed from the same parent materials (Esu et al., 2018). Usually, lower slopes have good quality soil physical properties because all material that are leached and eroded from summit slopes are accumulated there. Because of the movement of water in a hill slope soil exhibit a difference in physical properties because of vertical movement of water across a profile (FAO, 2019).

When planning to practice agriculture on hill land it is important to have good soil management practices which are best for land with different slope position. Soil physical properties and their genesis are directly affected by slope. A study of slope position and their physical properties is important because it played a role in saving the land and soil fertility (Esu et al., 2018).

Soil drainage and soil erosion are influenced by slope positions (Aytenew, 2015). Usually slope position have great impact on soil physical properties. Aytenew (2015) reported that slope position affected the development of soil which led to variation of soil physical properties along the slope. Bulk density and total porosity are greatly affected by slope. Middle slope positions usually had lower bulk density due to high clay content (Aytenew, 2015). Soil organic matter is greatly affected by different slope positions. Due to the movement of soil material because of erosion and deposition, lower slope position usually has high organic matter content compared to summit and mid slope positions (Khan et al., 2013).

2.5 Effect CA on soil properties

2.5.1 Bulk Density

The weight of oven-dry soil per unit total volume of dry soil is denoted by BD (Mckenzie et al., 2002). Bulk Density is used in the analysis of physical properties of the soil, and it is important in converting water percentage by weight to water percentage by volume and for calculating the total pore space.

Soil management practice such as ploughing temporarily decreased bulk density and increased pore space. Soils which are relatively low in total pore space and had high bulk densities are sandy soils. They had more compact particle arrangement, less aggregation and lower level of organic matter. Average bulk density of dense sub-soils is 1.8 g cm3. Soil management practices that involved the addition of organic material such as CA are encouraged to decrease the soil's bulk density (Evanylo and McGuinn, 2008). Under CA bulk density in the 0–30 cm layer of soil is usually lower because of high microbial activity and mulching using organic matter (Rai et al., 2018). Lower bulk density in CA improved water infiltration (Wang et al., 2014) and improve more solid and porous structure. Those pores are important to maintain good functioning of soil physical properties (Wang et al., 2014).

Mahanty (2015) noted that CA decreased bulk density due to the increase of soil organic matter which resulted in high infiltration rate. The decrease in soil bulk density under CA go with the duration of CA practices in the field (Muchabi et al., 2014). However, soil bulk density under CA differed with soil depth. Paliwal et al. (2017) found that soil bulk density increased in the 15-30 cm depth and decreased in the 0-10 cm depth under zero tillage. Where BD or porosity is more of a capacity indicator, the intensity of other parameters such as hydraulic conductivity, which affect water fluxes in the soil, is also important to consider.

2.5.2 Soil Organic carbon (SOC)

SOC, particularly the concentration of SOC at the surface, is the most essential soil health indicator. SOC aided in the storage of nutrients, the reduction of soil erosion, and the improvement of water infiltration (Lal, 2004). Land use and natural vegetation, soil texture, meteorological circumstances, topographic position, and the initial SOC stock all influence SOC concentration (Lal, 2004). SOC rate in soil is influenced by vegetation types, irrigation, crop rotation, integrated pest and nutrient management, and livestock (Lal, 2004). A positive SOC balance is accomplished at the field size by increasing organic matter supply to the soil and minimizing C losses through mineralization, leaching, and erosion, or by slowing the rate of SOC decomposition.

Good SOM is linked to improved plant nutrition, crop performance, and soil physical properties (greater aggregate stability, reduced bulk density, improved water holding capacity, enhanced porosity) (Musukwa, 2017). West and Post (2002) reported that SOC contents which are low under conventional tillage increased post adoption of zero tillage. Sisti et al. (2004), The concentrations of SOC to 100 cm depth under zero tillage are not significantly different from those under conventional tillage in a continuous sequence of wheat (winter) and soyabean (summer). Conventional tillage is reduced to N-fixing because of leaching of nitrate, due to SOM mineralisation stimulated by tillage.

CA improved building up of soil organic matter. According to Alves at al. (2013) soil organic matter changed over time in clay soil; usually from 0-20 cm layer under CA practice. Musukwa (2017) found that zero tillage, organic matter content differed from the method of planting; where he found that bed planting resulted in higher organic matter compared to flat planting method. In Zimbabwe, Musukwa et al. (2017) found that in a 0-20 cm layer of clay loam soils, all tillage strategies tested showed that soil organic matter increased with time. In the 0-15 cm layer of a sandy loam soil in India, Alves et al. (2013) discovered that no tillage with bed planting and no tillage with flat planting had 28 percent and 26 percent higher soil organic matter, respectively, than conventional tillage (CT). Musukwa et al. (2017) reported that Conservation Agriculture enhanced soil organic matter in a clayey loam (fine, mixed, thermic, Cumulic Haplustoll) soil in Mexico when compared to conventional tillage, but only at 0-5 cm soil depth.

2.5.3 Electrical conductivity

Soil EC refers to the measurement of soil salt amount which is present in the soil or salinity of soil (Adviento-Borbe at al., 2006). Electrical conductivity was one of the most important indicators of good yield and good soil health. It had an impact on plant nutrient present in soil, crop yields, crop quality and soil microorganism’s activity. Some soil processes including greenhouse gases emission, nitrogen oxide and carbon dioxide were affected by EC (Adviento-Borbe et al., 2006).

Under zero tillage practices gradual accumulation of salt was observed next to soil surface during rice growth stage, compared to conventional tillage (adviento-Borbe et al., 2006). Furthermore, there was a significant interaction between soil tillage and soil depth. There were no differences in soil electrical conductivity between tillage systems in the 5-15 cm layer. Tillage practices had little effect on EC concentrations in some cases. Regardless of tillage, extractable Na increased with depth. (Franzluebbers and Hons 1996).

2.5.4 Aggregate stability

Soil structure was important in the determination of crop production and proper functioning of soil Passioura. (1991). Soil structure is defined as the size, shape, and arrangement of solids and voids, as well as the ability to support root growth. The degree of aggregate stability was frequently used to describe soil structure (Bronick and Lal 2005).

Dry aggregate size distribution of soil was improved under no till with the residue retention compared to conventional tillage (Govaerts et al., 2009). Giller et el. (2009) reported that Conservation Agriculture (CA) increased aggregate soil stability in both high clay soil and low clay soils compared with conventional agriculture. Covering or mulching soil using organic matter support the formation of stable aggregates and soil structure and reduce soil erosion and degradation (Musukwa, 2017).

Nyamangara et al. (2015) investigated the impact of basin-based Conservation Agriculture (CA) on selected soil quality indicators and discovered that, as compared to conventional agriculture, water stable aggregates rose by 19% and 8% in high clay soils and low clay soils, respectively. They attributed this to Conservation Agriculture's better soil organic matter build-up and less soil disturbance (tillage). This backed up previous researchers that suggested soil organic content lessens the danger of erosion by enhancing the production of stable aggregates and soil structure.

2.5.5 Soil total porosity

Soil porosity is the amount of open space between soil particles (Kay and Vanden 2002). Different pore sizes were generated by different tillage systems and were influenced by root growth as well as burrowing fauna (Kay and Vanden, 2002). Root penetration and water movement in the soil were related to soil porosity. Pore size and shape were influenced by different tillage systems. Under CA mulching using straw increased total porosity of soil (Tangyuan, 2009). Increase in soil bulk density resulted in the loss of pore space which was corrected by introducing zero tillage practice. Other researchers have indicated that increased porosity of top 5 cm layer of soil was caused by organic matter build-up (Hulugalle, 1999). The adoption of CA was important in limiting the possible loss of pore space.

2.5.6 Water holding capacity

Soil WHC is the amount of water that soil can hold. Pore size and distribution determined the movement and storage of soil water (Thierfelder et al., 2009). The presence of macropores and mesopores fraction in the topsoil layer due to organic matter determined the soil water holding capacity (Shaxson 2003). In a study by Thierfelder et al. (2009) CA increased soil water holding capacity. Similarly, Mlozo-Banda et al. (2015) reported similar results when they carried out a study to assess impacts of CA on soil properties in small scale farms. CA and soil management practice that increase the organic matter content in the soil increased WHC of the soil (Hatfield et al., 2001). Other researchers reported that WHC of the soil was high in CA compared to conventional tillage in different locations (D'Haene et al., 2008).

2.5.7 Infiltration rate

In soil water management and water resource conservation methods, water infiltration into the soil is a critical issue. The process by which water on the ground surface enters the soil is known as infiltration. As a result, it calculated the amount of runoff over the soil surface during irrigation and precipitation, as well as infiltration, which was critical for soil and water conservation. The infiltration rate of a soil, and consequently its ability to withstand excessive rainfall or irrigation, was determined by the soil's properties (Oku et al., 2011). Poor infiltration suggested a greater risk of runoff and erosion, both of which had an impact on the amount of water stored in the root zone of a plant (Thomas et al., 2020). This made it harder for the soil to supply the crop's essential water demand.

Furthermore, because soil infiltration behavior has a direct impact on critical variables such as inflow rate, length of run, application duration, and depth of percolation, surface irrigation system design, operation, and management are heavily reliant on it.

Infiltration enabled the soil to temporarily store water, allowing plants and soil organisms to absorb it. Poor management had the potential to limit penetration. Water cannot easily penetrate the soil in these conditions, so it runs off or collects in ponds on the surface, where it evaporated. Thus, less water was held in the soil for plant growth, and plant production declined, resulting in lower organic matter in the soil and reduced soil structures, which further reduced infiltration rates (Haghnazari et al., 2015). Suggested by Haghnazari et al. 2015 that management measures such as increasing plant cover, particularly of species that had beneficial impacts on infiltration, reducing compaction by avoiding intensive grazing, and avoiding the use of machinery when the soils were moist be considered.

Chapter 3

3. Materials and methods

3.1 Study site description

The study was conducted at Mutanga wa Ndodzi Agricultural Co-operative farm. It is located at Tshivhilwi village 22°50'56"S and 30°38'36,7"E, Vhembe District Limpopo province of South Africa (Figure 1). Annual average temperature and rainfall is 21.4ºC and 642 mm, respectively. The farm was established in 2013 and practices CA. The farm consists of two blocks of land, one is used for crop production and the other which is directly opposite across the river is natural grassland. The field used for crop production was tilled once in 2013 using a mouldboard plough when the farm was established. Thereafter conservation agriculture was practiced. The form of conservation agriculture is described in the next paragraph.

CA at this farm consist of minimum tillage. Mulching or covering the ground with crop residue is only done after harvesting maize, where maize stalks are left on the ground (Figure 2). A few days before planting poultry manure is applied especially during planting of cabbage and spinach at the rate of about 2 t/ha. Drip irrigation pipes are laid before planting so that the planting stations can be identified easily. A digging fork is used to open a hole for planting. After planting, fertilizer is applied based on crop requirements usually 30 g of 2:3:2 (14) fertilizer per planting station. Two methods of weeding are used depending on the type of crop which is planted. For maize, round up® (Glyphoste) is used for weeding control and sometimes weeds are removed by hand. Hand hoeing is used for weeding in cabbage and spinach.

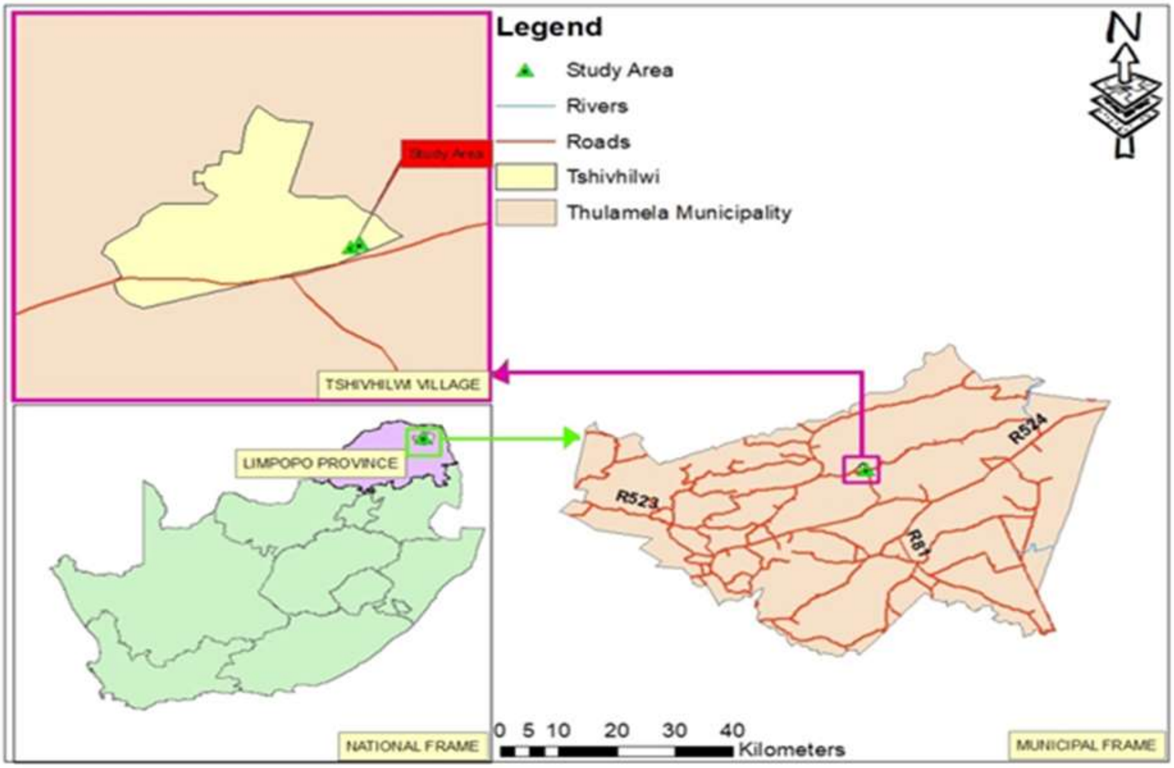

Figure 1: Study area

Figure 2: Mulching with crop residues (maize stalks)

3.2 Soil sampling

Two fields with similar soil type (Vertisol) were chosen. The fields are separated by a river and are directly opposite each other. One field was under natural grassland (NG) and was used as the control while the other was under CA. Both fields were subdivided into ten evenly spaced transects. Auger soil samples were collected from 0-10 and 10-20 cm depth along the transects from the summit (S), middle slope (MS), and lower slope (LS) positions of both fields and core ring was used to collect bulk density sample. Therefore, six soil samples were collected from each transect giving a total of 120 samples (3 slope positions × 20 transects × 2 depths) samples from both CA and NG fields. Slope gradient was measured at each slope position by using a 100 m tape measure in combination with a GPS (Germin GPS Map 65s handheld).

The collected soil samples were air-dried, cleared of visible root or organic residues and passed through a 2-mm sieve. Crushed and sieved soil sample of aggregate size <2mm was used to determine the selected soil physical properties except for aggregate stability (AS). Soil samples meant for the determination of AS were collected using a spade and transported to the laboratory with minimum disturbance to preserve their natural aggregates.

3.3 Soil analysis

3.3.1 Bulk density

A core sampling method was used to determine soil bulk density (Black and Hartge, 1986). Soil samples were collected using a core sampler, which consists of a metal cylinder with one end sharpened and a sampler head with a handle for pushing the cylinder into the soil. Five-centimeter-diameter and five-centimeter-high soil core samples were gathered and taken to the lab for additional processing. In the laboratory, the core was weighed before drying and reweighed after drying in oven model Series 2000 at 105°C for 48h.

Soil BD was calculated using the following equation:

BD (g/cm^3) = Dry soil weight (g) / Soil volume (cm^3) …………………. (1)

3.3.2 Soil organic carbon

The modified wet oxidation method was used to determine SOC concentration (Nelson and Sommers 1982). In the digester tube, 0.1 to 0.5 g of soil was mixed with 5 ml of potassium dichromate solution and 7.5 ml of H2O4. The digest was transferred to 100 ml conical flask, and 0.3 ml of the indicator solution and the digest titrated with ferrous ammonium sulphate solution (Figure 3).

Soil organic carbon (%) was calculated using the following equation:

Organic carbon (%) = (T×0.2×0.3)/ (sample weight) ……………………………………………. (2)

Where T = the titration volume

***Figure 3**: soil organic carbon determination Modified wet organic oxidation procedure.*

3.3.3 Soil electrical conductivity

Electrical conductivity was measured with glass electrode (EC probe) professional EC meter (CDM 210 model) in 1:5 ratio soil water suspension as per the procedure described in the Non-Affiliated committee (1990). Air dry soil (10 g) (<2mm) was weighed into a bottle. A volume of 50 ml of deionised water were added and the soil sample left in the mechanical shaker at 15 rpm for 1 hour to dissolve soluble salts. Calibrated EC meter was used to measure electrical conductivity (non-Affiliate committee, 1990).

3.3.4 Aggregate stability

Soil aggregate stability (AS) was determined by the wet sieving method (Kemper, 1986). Sieve mesh were filled with 4 g of soil aggregate. Aggregate was pre- moistened for 5 minutes before submerging. The first set of cans were fill with distilled water and placed in the sieve can holder. Sieve mesh with aggregate was submerged into distilled water cans for 3 minutes. Cans containing particles and aggregates fragment that have broken loose from the aggregate and come through the sieve were replaced with other set of cans filled with dispersing solution (2 g sodium hexametophosphate/L) for pH >7 soil. Sieves mesh with aggregate were submerged again into cans filled with sodium hexametophosphate until only sand particles and roots left in the sieve. Both set of cans were placed in an oven (Series 2000) at 110°C until water evaporated. The weight of the material in each can was determined by weighing the can. Soil aggregate stability was calculated using:

$$\mathrm{WSA}=\frac{wds}{(wds-wdw)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where: WSA= is the index of water stable aggregates

wds= is the weight of aggregates dispersed in the dispersing solution (g)

wdw= is the weight of aggregate dispersed in distilled water (g)

3.3.5 Soil porosity

Total soil porosity was determined by using indirect measurement, through determination of soil particle density (Pd). The pycnometer flask was half filled with air-dry soil and weighed. Water was added to the flask slowly until full and the soil and water thoroughly mixed. The full flask was weighed. The flask was refilled with water only and weighed.

Particle density was calculated using this equation:

Pd = mass of dry soil/ volume of dry soil………………………………………………… (4)

After determination of soil particle density, soil porosity was calculated by this equation:

$V_f = 1 - \frac{Pb}{Pd}$ ……………………………………………………………………………… (5)

Where V_f = porosity

Pb = bulk density

Pd = particle density

3.3.6 Water holding capacity

A mass of 25 g of soil was saturated with water in a glass funnel and allowed free drainage for 48 hours, with the top surface covered by plastic to prevent evaporation. After 48 hrs the weight of the soil was measured and water holding capacity was calculated by using the following equation:

WHC= (weight of saturated drained soil – weight of dry soil) / weight of dry soil…………. (6)

3.3.7 Infiltration rate

Double ring infiltrometers, consisting of two concentric rings, were used to measure the infiltration rate. The inner and outer rings had a diameter of 32 cm and 57 cm respectively. The rings were driven 5 cm into the soil using a metal plate and sledgehammer (Figure 4a). At CA site the rings were filled with maize stalks for mimicking CA and water was added up to 20 cm above the soil surface (Figure 4b). The rings were re-filled to the 20 cm head level each time when the head approached 5 cm above the soil surface. Water level was recorded at the increment of 2, 3, 5, 10, 15, 20, 30, 45 and 60 minutes and then at 30 minutes interval after that for the calculation of infiltration rate and cumulative infiltration. The measurements were designed to determine the steady-state infiltration rate, and this was accomplished when the amount of water infiltrated remains constant over time.

Figure 4a: double ring infiltrometer

Figure 4b: double ring infiltrometer with mulch

3.3.8 Soil particle size distribution, soil texture and soil pH

Soil particle size distribution was determined using hydrometer method (Bouyoucos 1962). Mass of 50 g of air-dry soil was weighed into 400 ml beaker and saturated with distilled water, 10 ml of Calgon solution was added and allowed to stand for 10 minutes. Suspension was transferred in to dispersing cup mixed for about 2 minutes with an electric high-speed stirrer. Suspension was transferred into gradual cylinder and filled with 1000 ml of distilled water. Hydrometer reading was taken at 40 seconds and temperature reading was taken by use of thermometer. The cylinder with suspension left to stand without disturbance for 2 hours, after 2 hours' suspension was stirred 10 times and hydrometer reading and temperature was recorded. Percent (%) sand, clay and silt were calculated.

Soil pH was measured by weighing a mass of 10 g of soil sample was weighed. A volume of 50 ml of denoised water was added. The mixture was stirred for 10 minutes and allowed to stand for 30 minutes and stirred again for 2 minutes. A pH meter (model PHS-25PH Meter) was used to measure the pH of soil suspension in 1:5 soil water suspension (Rhoades, 1982)

3.4 Data analysis

The data collected was subjected to two-way analysis of variance (ANOVA) Statisix software, version 10 package. The treatment means were separated by least of significant difference (LSD) when the analysis of variance F- test was significant at $P \leq 0.05$ probability level.

Chapter 4

4.1 Results

4.1.1 Site and soil characteristics

At 0-10cm depth, there was no pattern in particle size distribution under CA across all slope positions. However, the summit slope position recorded the highest sand percentage (48%) whilst the middle slope position recorded the highest percent clay (46%) (Table 1). A similar pattern was repeated under NG site at summit and middle slope positions. However, clay content was highest at lower slope position (42%) which recorded a clay texture.

Table 1. Percent sand, clay, silt and textural class at 0-10 cm depth at the study site.

Management	% Sand	%Clay	%Silt	Textural Class
CA				
Summit	48	40	12	Sandy clay
Middle	40	46	14	Clay
Lower	38	45	17	Clay
NG				
Summit	62	30	8	Sandy Clay loam
Middle	50	30	20	Sandy Clay loam
Lower	40	42	18	Clay

At 10-20 cm depth, it was observed that percentage sand decreased whilst percentage clay and silt marginally increased from summit to lower slope position on CA site (Table 2). The highest percentage sand (52%) was observed at the summit slope position whereas, highest percentage clay (40%) was observed at the middle slope position (Table 2). A nearly uniform soil particle size distribution pattern was observed under NG site where a constant clay percentage (36%) was recorded at summit and middle slope positions. However, the NG site was sandy compared to the CA site.

Table 2. Percent sand, clay, silt and textural class at 10-20 cm depth at the study site.

Management	%Sand	%Clay	%Silt	Textural Class
CA				
Summit	52	36	12	Sandy Clay
Middle	44	40	16	Clay
Lower	40	43	17	Clay
NG				
Summit	56	36	08	Sandy clay loam
Middle	54	36	10	Sandy Clay
Lower	56	32	12	Sandy Clay

The results showed that CA site summit slope position recorded the lowest gradient (9.3%) compared to NG site. However, it was observed that CA site had slightly higher slope gradient at middle slope (7%) compered to NG site (Table 3).

Table 3: Slope position (lower, middle and summit) gradient percent at the study area

	Management	
Slope position	%CA	%NG
Lower	5.3	4.76
Middle	7	6.8
Summit	9.3	9.54

4.1.2 Bulk density

A significant management × slope position interaction effect (*P<0.01)* was observed on BD (Figure 5a and 5b). The lowest BD (0.76 g/cm3), was observed at the CA lower slope position at 0-10 cm, followed by middle slope and summit slope position. However, there was no significant difference between BD on the middle and summit slope positions at 0-10 cm depth.

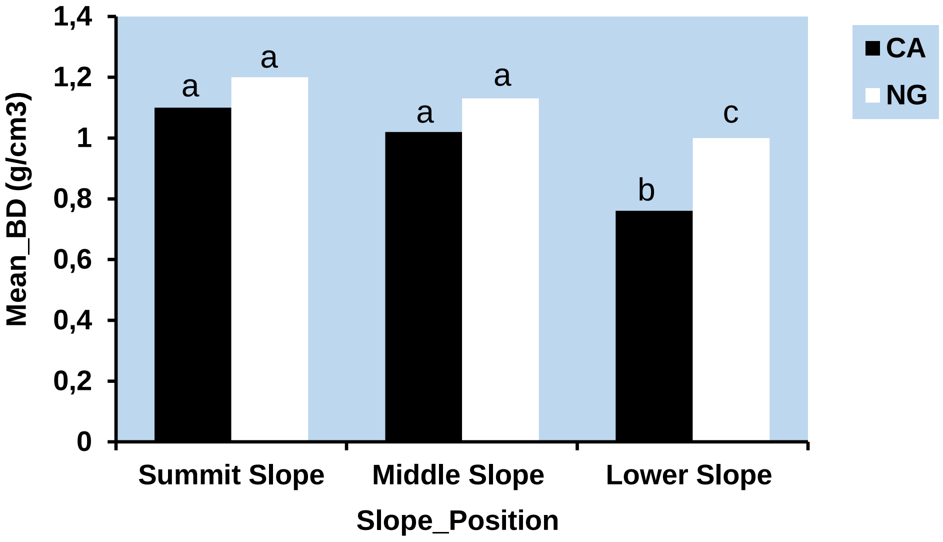

Figure 5a: **BD (g/cm3) as a function of interaction between management and slope position (0-10cm soil depth)**

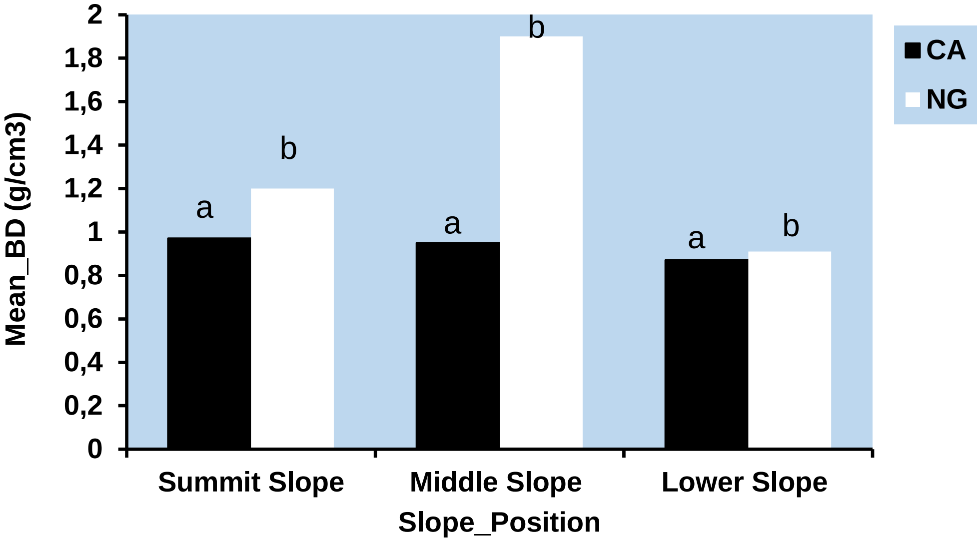

Figure 5b: **BD (g/cm3) as a function of interaction between management and slope position (10-20cm soil depth)**

4.1.3 SOC (soil organic carbon)

A significant management × slope position interaction effect (*P<0.001)* was observed on soil organic carbon at 0-10 cm soil depth (Figure 6a). Organic carbon was significantly higher (*P<0.01*) on lower and middle slope of CA than NG sites. The highest SOC content of 1,19% was obtained at the CA lower slope position whilst the lower was observed at the summit slope of both CA and NG sites. At 10-20 cm soil depth, CA recorded a significantly higher OC content than the NG site only at the middle slope position (Figure 6b).

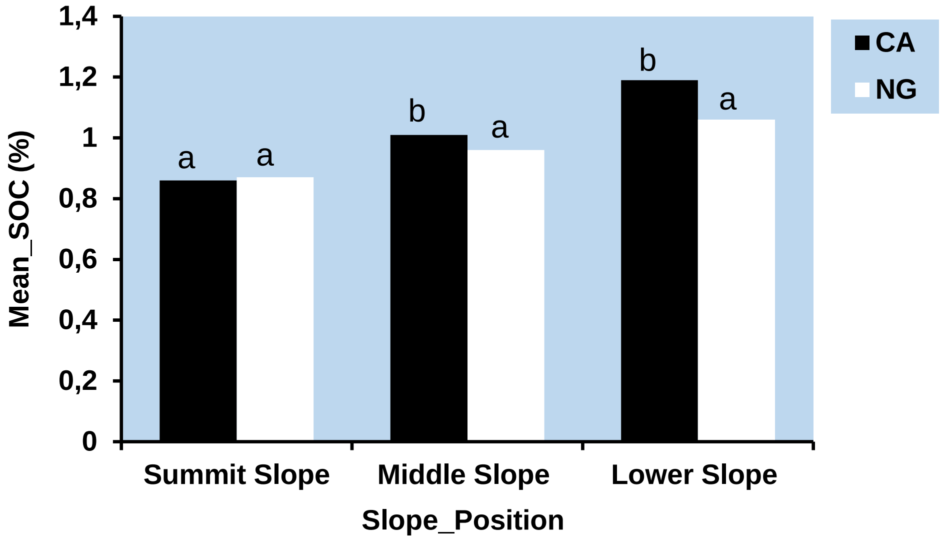

Figure 6a: **SOC (%) as a function of interaction between management and slope position (0-10cm soil depth)**

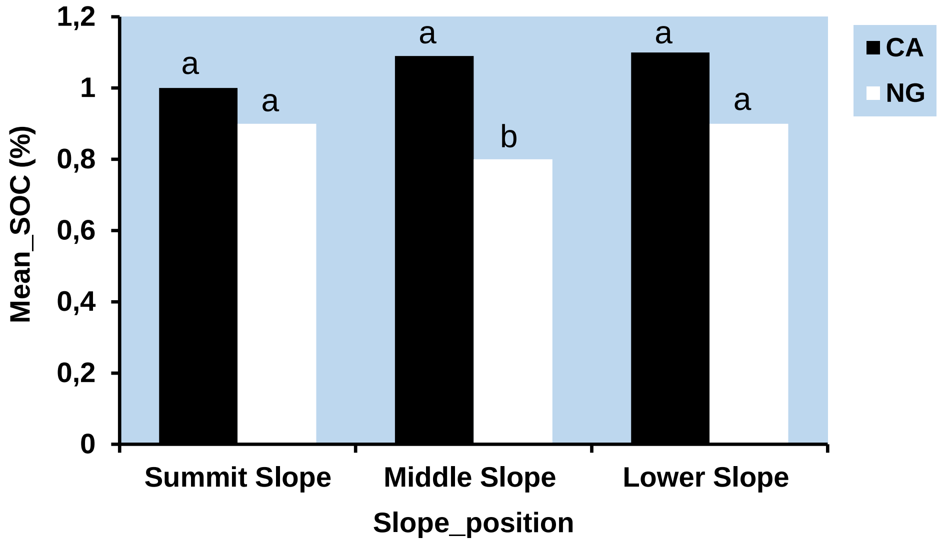

Figure 6b: **SOC (%) as a function of interaction between management and slope position (10-20cm soil depth)**

4.1.4 EC (Electrical Conductivity)

There was a significant effect (*P<0.01*) between management × slope position interaction at 0-10cm and 10-20cm soil depth (appendix A and B). The CA site recorded highest EC at middle and lower slope positions compared to the NG site. The highest EC at lower slope of CA site and the difference was significant between the two sites (Figure 7b). A similar trend was observed at the middle and lower slope positions.

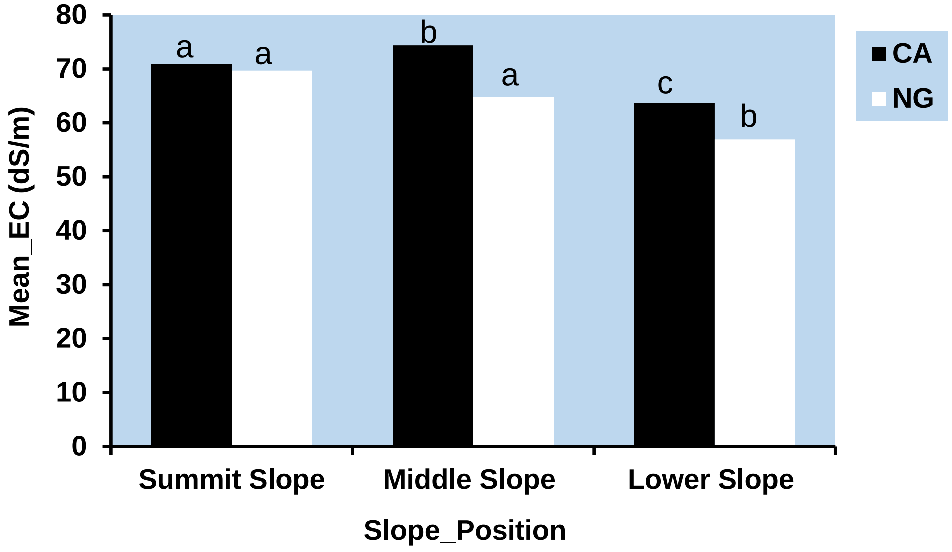

Figure 7a: **EC (ds/m) as a function of interaction between management and slope position (0-10cm soil depth)**

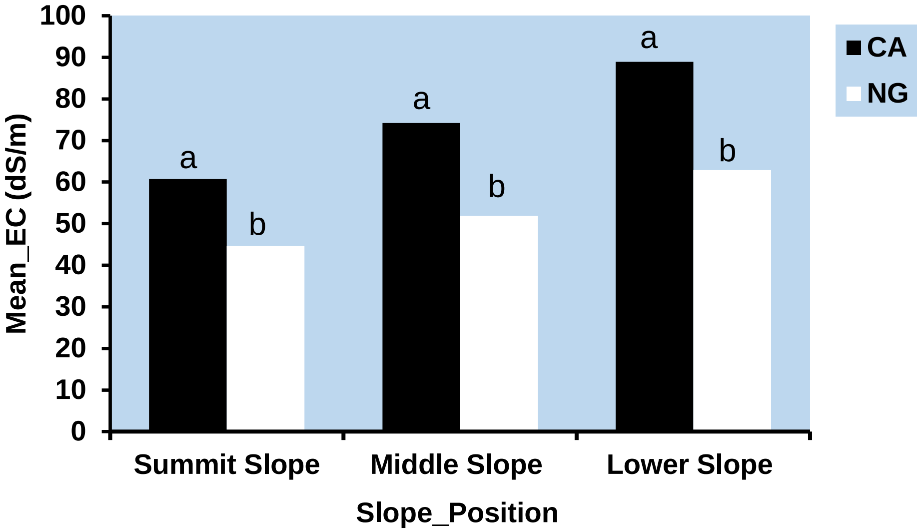

Figure 7b: EC (ds/m) as a function of interaction between management and slope position (0-10cm soil depth)

4.1.5 AS (aggregate stability)

A significant management × slope position interaction effect (*P<0.05)* was observed on soil aggregate stability (Figure 8a and 8b). The CA site had higher AS than NG site at all slope positions at 0-10 cm depth. CA lower slope had the highest soil aggregate stability percent followed by middle and summit slope. There was also a significant management × slop interaction (*P<0.01*) at 10-20 cm depth (Figure 8b). CA site recorded higher AS than NG at all slopes positions.

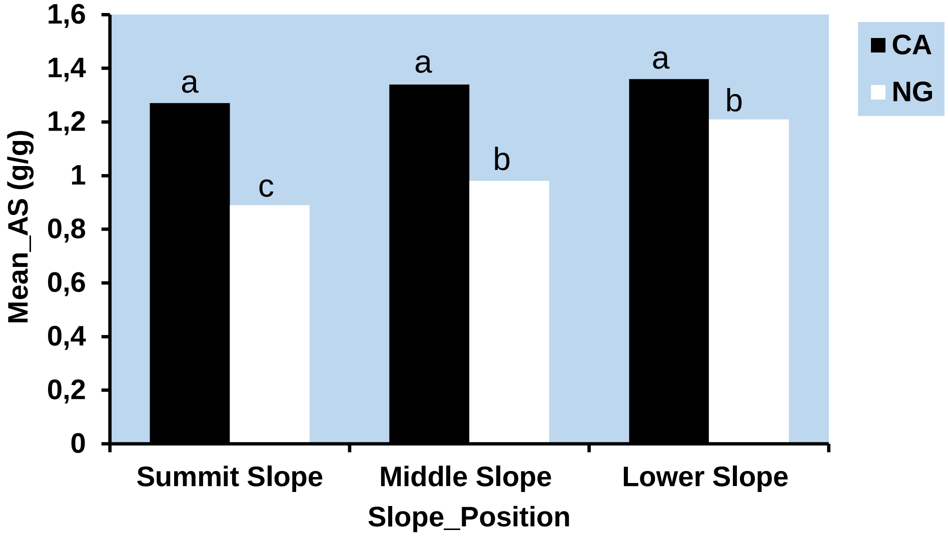

Figure 8a: AS (g/g) as a function of interaction between management and slope position (0-10cm soil depth)

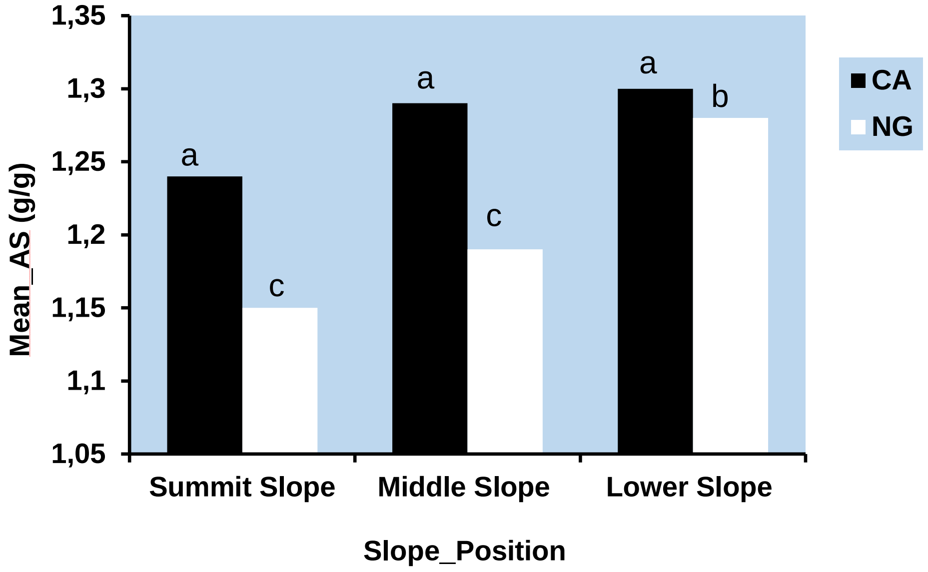

Figure 8b: AS (g/g) as a function of interaction between management and slope position (10-20cm soil depth)

4.1.6 Vf (Total soil porosity)

There was a significant (*P<0.05*) management × slope position interaction at 0-10cm soil depth (Figure 9a). The CA site recorded higher total porosity than the NG site at all slope positions. The highest total porosity was observed at the CA summit slope position followed by the lower slope and middle slope, in that order. There was also a significant interaction effect between management and slope position at 10-20cm soil depth (*P<0.001*) (Figure 9b) although there was no significant difference between the middle and summit slope positions at 10-20 cm soil depth (Figure 9b).

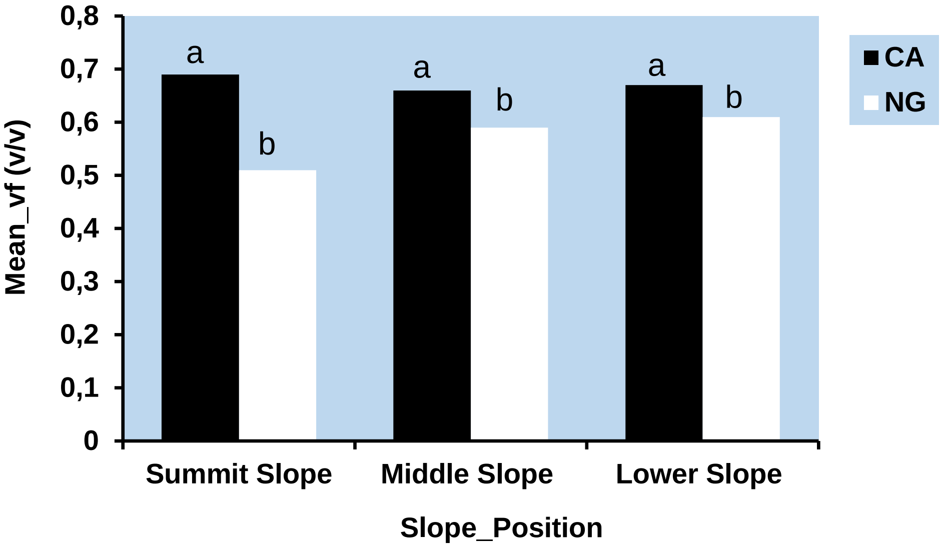

Figure 9a: Vf (v/v) as a function of interaction between management and slope position (0-10cm soil depth)

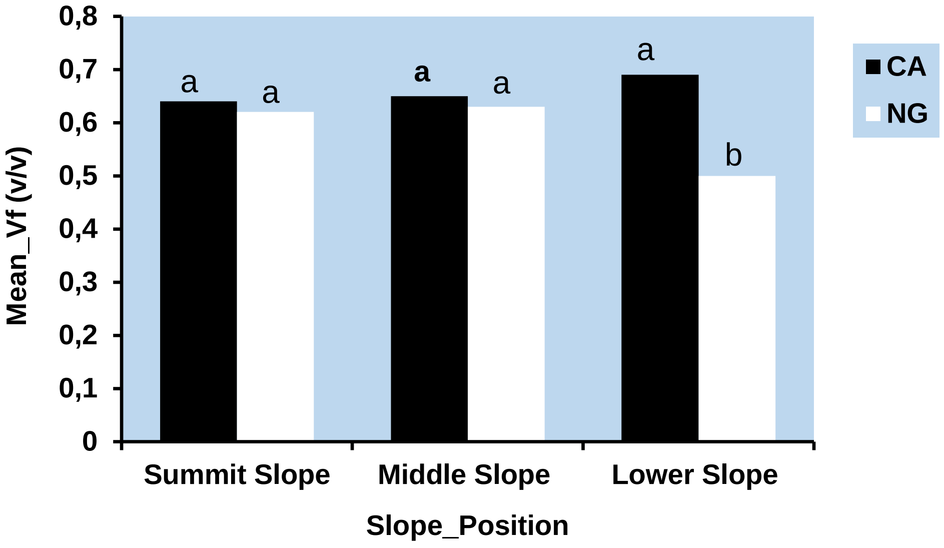

Figure 9b: Vf (v/v) as a function of interaction between management and slope position (10-20cm soil depth)

4.1.7 WHC (soil water holding capacity)

A significant management × slope position interaction effect (P<0.01) was observed on water holding capacity at 0-10 cm depth. CA site exhibited higher WHC than the NG site at all slope positions. CA middle and lower slopes had the highest WHC followed by the summit slope position at 0-10 cm depth (Figure 10a). A significant management x slope position interaction effect (*P<0.01*) was observed at 10-20 cm soil depth. The highest WHC was observed at lower slope position, followed by middle slope and summit slope position, in that order.

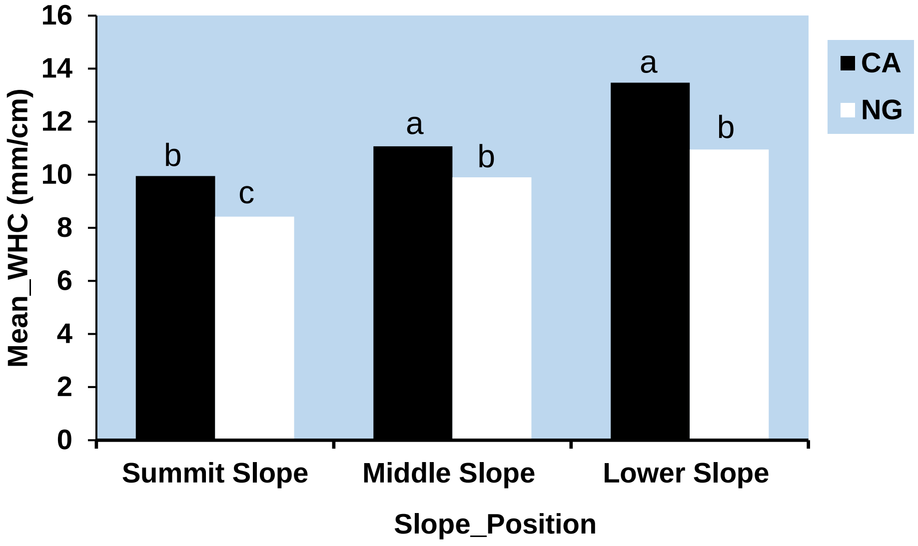

Figure 10a: WHC (mm/cm) as a function of interaction between management and slope position (0-10cm soil depth)

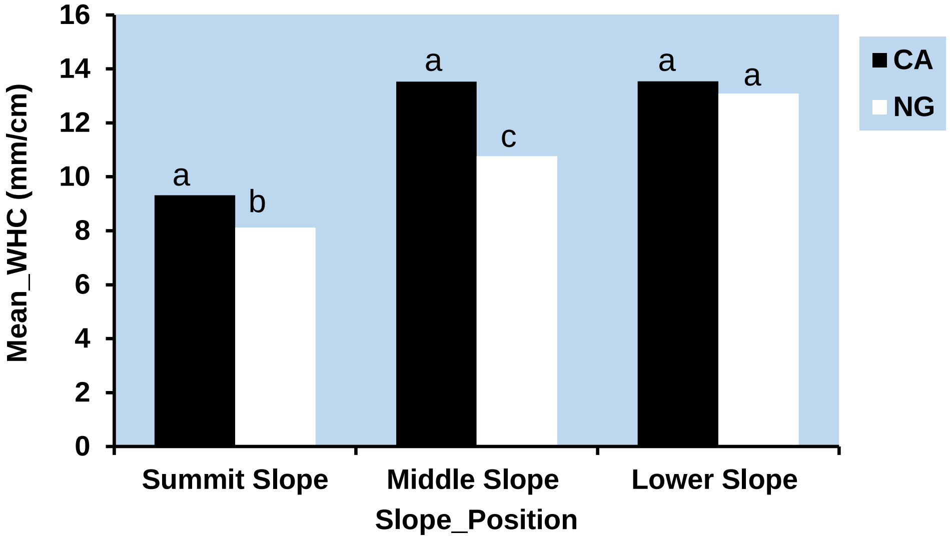

Figure 10b: WHC (mm/cm) as a function of interaction between management and slope position (10-20cm soil depth)

4.1.8 Final infiltration rate (IR) and Cumulative infiltration (CI)

A significant management × slope position interaction effect ($P<0.05$) was observed on final IR (Figure 11a). The significant difference between the two management systems was observed at lower and middle slopes. Similarly, a significant interaction effect ($P<0.01$) between slope position and management was observed on CI (Figure 11b). Summit slope of CA site was associated with the higher CI (54.23 cm) compared to NG site (48.01 cm).

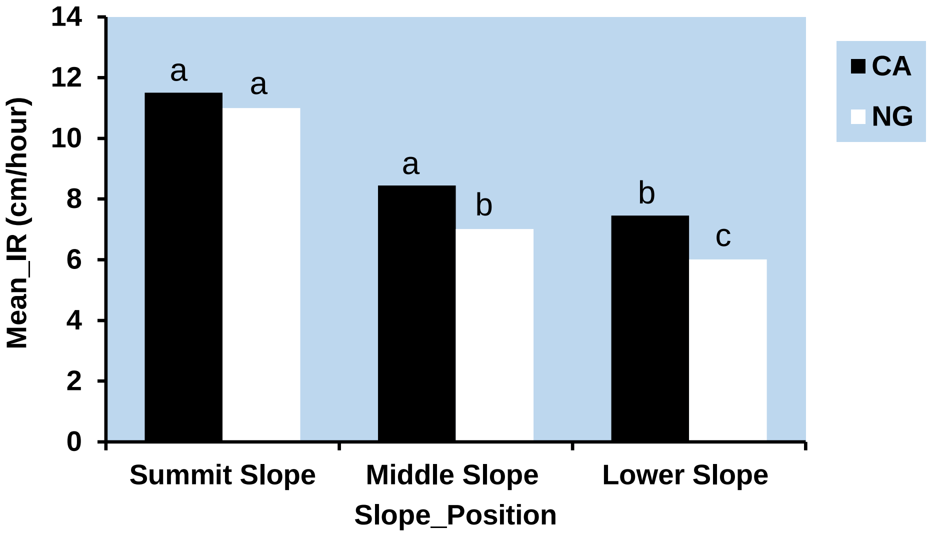

Figure 11a: IR as a function of interaction between management and slope position

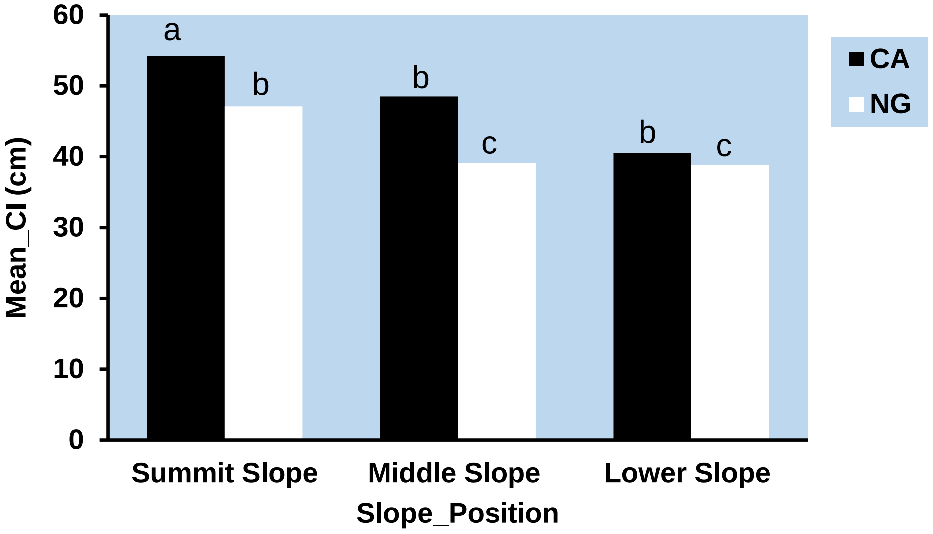

Figure 11b: CI as a function of interaction between management and slope position

Chapter 5

5. Discussion

5.1 Effect of conservation agriculture and slope position on

5.1.1 BD (Bulk density)

The soil BD generally reflects the material's state of compaction and, indirectly, total porosity. When the BD is high, the soil does not contain pores necessary for root growth, water capacity is reduced and flow of fluids (Schwyter, 2021). Significant effect in BD is observed under CA and NG site at 0-10 cm and 10-20 cm (Appendix A & B). Suryawanshi et al. (2018) previously reported that land use significantly affects the soil bulk density.

A significant management and slope position interaction effect is observed on BD (appendix and B). The lowest BD (0,76 g/cm3) is observed at the CA lower slope position at 0-10 cm. The lower BD under CA at lower slope position is possible due to more aggregation and higher SOC content at the soil surface. The lower value of BD at all slope positions of CA site from 0–10 cm, and 10–20 cm of soil depth demonstrates that the soil at the CA management site has high voids, and the particles are not compacted, and this demonstrates that CA management at all slope positions has good impact on soil health improvement. As a result, the flow of water and infiltration process is improved as well as roots growth (Mermound, 2010). The exceptional decrease of BD from summit slope to lower slope positions at CA site management is due to considerable improvement in SOM, this supports the finding of Maryam et al. (2011).

It was discovered that the clay and silt content increased while the sand content decreased down the slope. (Table 1 & 2). This observation agrees with the finding of Abadllah et al. (2017). Abadllah et al. (2017) reported that when there is little soil erosion, finer particles become suspended in the accumulating water and are transported down the slope, leaving coarser materials at the top of the slope with less micro pore space and higher bulk density. In contrast, the suspended finer particles are transported down the slope, where they accumulate at the bottom, increasing the clay and silt content with lower bulk density at the bottom slope position.

5.1.2 SOC (Soil Organic Carbon)

A significant management and slope position interaction effect is observed on SOC at 0-10 cm and 10-20 cm (Figure 6a & 6b). SOC is significantly higher on lower slope position of CA than NG. The highest SOC content of 1,19% is obtained at the CA lower slope position. The reason for this can be mostly due to minimal soil disturbance and consistent organic matter intake though mulching. This can be due to the downward movement of residue utilized for mulch from the top slope to the lower slope, where it accumulates. The findings are consistent with those of Jagadamma et al. (2019), who discovered a significant increase in total SOC concentration in the surface layer of CA-treated soils. The increase in SOC in the soil's upper layer can be due to a combination of adding organic wastes such as chicken manure practiced on this farm to the soil surface while not affecting the existing organic matter reserves beneath the surface. The increase in SOC is great when comparing the 0-10 cm soil depth of the CA site to the 10-20 cm soil depth of the CA site (Figure 6b). CA techniques practiced on all slope positions has higher SOC content in the 10-20 cm soil depth, which can be attributed to crop residue retention on the soil surface, increased plant biomass output, which results in more root residues in the system, and a delayed SOM decomposition rate due to minimal soil disturbance. Crop residues increase biological activity, reduce nutrient release into the soil, and help to regulate soil hydrothermal cycles. In the first 10-20 cm of soil depth, a combination of crop residue and low tillage can retain more carbon (Valenzuela, H. 2020). Differences in crop rotation (maize, green beans and cabbages) based on slope position in the CA site may also have an impact on SOC increasing rate at 0-10 cm to 10-20 cm soil depth.

Furthermore, the management practice (CA) has the potential to improve C and N cycling as well as soil aggregation, which increases the amount of organic carbon sequestered in the soil

(Thierfelder et al., 2015). CA is a critical agricultural management practice that can improve SOC content. Findings are supported by Hossein et al. (2015), who reported that the slope position and CA practice has a significant impact on SOC content. Based on our findings, it cannot be inferred that the slope gradient is the primary determinant of SOC content, but that other factors such as land use/cover, slope aspect, management strategies, soil type, depth, and elevation play a significant role (Valenzuela, H. 2020). Based on our findings from this study, it is possible to conclude that the slope position and management systems which are CA and NG had a significant impact on distribution of SOC.

5.1.3 EC (Electrical Conductivity)

EC is a significant measure of soil physical quality. It is the soil electrical conductivity resistance to disintegration under the effect of water, wind, and management, and it has an impact on a variety of physical, biological, and chemical processes in the soil. (Amézketa, 1999).

There is a significant effect of management and slope position interaction at 0-10cm and 10-20 cm soil depth on EC (Figure 7a and 7b). There is no significant difference at summit slope. Significance is observed at middle slope and lower slope positions and the highest EC is recorded at the middle slope (74.4 dS/m) at CA site at 0-10 cm soil depth. The CA site recorded the highest EC at middle slope (74,24 dS/m) and lower slope (88,91 dS/m) at 10-20 cm soil depth. The findings support those of Farmanullah et al. (2013), who observed an increase in soil EC down the slope, as well as a similar increase in soil EC down the profile. Because the soil is covered throughout and there is minimal soil disturbance. One of the advantages of CA is that it reduces surface runoff. As the buildup of water, soluble cations, and anions movement down the slope is reduced, this could be another reason for the increasing trend in soil EC down the slope. The percolation of soluble cations and anions down the soil profile could explain the increasing trend in soil EC down the profile. Farmanullah et al. (2013) also observed that the increase in EC with depth is attributable to the downward flow of soluble ions, as they had hypothesized.

The most essential aspect of EC for fertility is that it indicates the availability of nutrients in the soil (Farmanullah et al., 2013). The higher the EC, the more negatively charged sites clay and organic particles must have in the soil, and thus the more cations positively charged particles must be stored in the soil (Farmanullah et al., 2013). The EC of soil is highly correlated with particle size and soil texture. Because clay soil textures have high EC, this could be the cause of the high EC at all slope position of CA site and NG site.

5.1.4 AS (aggregate stability)

The results from this study showed significant management and slope position interaction effect *on* soil AS (Figure 8a and 8b). The CA site has higher AS than NG site at all slope positions at 0-10 cm depth. CA lower slope (1,36 g/g) has the highest soil aggregate stability percent followed by middle (1,34 g/g) and summit slopes (1,27 g/g). As pattern observed in this study could be attributable to limited tillage and crop rotation, which are important variables in the CA system. Due to stable soil aggregates and soil biodiversity, soil under CA at all slope position at the study area have better soil strength, which helps to increase the amount of water and nutrients available to growth and development plans (Rilling et al., 2017). CA method which was practiced at the farm could have increased soil aggregation by limiting soil disturbance due to tillage avoidance/minimization and residue retention. The results are in line with the finding reported by Jayaraman (2022) who reported that agricultural residue retention aids in soil particle binding and residue development of macro aggregates. Higher aggregate stability at lower slope position can be attributed to higher SOM content due to surface cover. The slight decrease in soil aggregate stability from summit to lower slope is attributed to a lower degree of soil erosion due to crop residues covering the land. The findings of this study are in line with the findings of Rilling (2017) who reported the increase of soil aggregate stability when there is decrease in bulk soil.

5.1.5 Soil porosity

There is a significant effect of management and slope position interaction at 0-10 cm soil depth (Figure 9a). The CA site records higher total porosity than the NG site at all slope positions. The results indicates that the highest total porosity is observed at the CA summit slope position (0,69 v/v) followed by the lower slope (0,67 v/v) and summit slope (0,66 v/v), in that order. There was also a significant interaction effect between management and slope position at 10-20 cm soil depth (Figure 9b) although there is no significant difference between the middle and summit slope positions at 10-20 cm soil depth (Figure 9b). The results suggests that CA-based management approaches have an impact on soil porosity, particularly in the surface soil layer. The impacts of CA-practices and slope position on soil porosity vary based on soil texture, climate, and the length of time after they are applied (Abdallah et al., 2017). At the CA site, the increased amount of crop wastes absorbed by the soil year after year promotes the formation of stable soil aggregates and increases soil organic matter, potentially increasing soil resistance and resilience to pore deformation. (Indoria et al., 2020). Furthermore, increased biological activity in CA practices improves soil organic matter status through a variety of micro-organism activities such as fungal hyphae development and exudates released during bacterial growth, as well as macro-organism activities such as earthworm or termite activity, resulting in a more stable soil pore system with improved aggregate size and facilitating crop root exploration of the soil profile. (Indoria et al 2020). Sasal et al., (2006) observed that overall porosity in the surface soil layer (0–15 cm) was 3.5 percent higher under conventional agriculture than it was under CA-based management approaches. Based on the results of this study, short-term CA-based management strategies enhanced the fraction of small pores while reducing overall and macro-porosity depending on slope position.

The high bulk density (Appendix A & B) decreases clay content (Table 1), and low organic matter content may be responsible for the slightly different in total soil porosity found at summit, lower and middle slope positions. However, the lowest slope location with the highest clay content (Table 1) has the higher total soil porosity, indicating that clay concentration has a beneficial impact on total soil porosity. Aytenew (2015), reported similar results, recording the lowest total soil porosity on moderate slope area and the highest total soil porosity on gently sloping area. This suggests that the soils from all slope position under CA in the study area are physically fertile.

5.1.6 WHC (soil water holding capacity)

A significant management and slope position interaction effect is observed on water holding capacity at 0-10 cm depth. CA site exhibited higher WHC than the NG site at all slope positions. CA lower (13.47 mm/cm) and middle (11.08 mm/cm) slopes have the highest WHC followed by the summit slope position (9.95 mm/cm) at 0-10 cm depth (Figure 10a). the finding also reports that there is a significant management and slope position interaction effect which was observed at 10-20 cm soil depth except the lower slope position. The highest WHC is observed at lower slope position (13.54 mm/cm), followed by middle slope (13.53 mm/cm) and summit slope position (9,32 mm/cm), of CA site in that order. This can be due to the improved aggregate stability, in conjunction with residue retention in CA systems, that has a positive impact on soil water storage. Improvements in aggregate stability near the profile's surface and the larger number and continuity of macropores available to quickly transfer water into the soil profile in the absence of tillage are frequently blamed for increases in infiltration (Page et al., 2020). The results observed in this study contradict the findings of Masukwa (2018), who found no significant differences in WHC under CA with the highest average value of WHC (12.56 mm/cm) in topsoil. In contrast, soil water holding capacity is significantly higher on NG than CA at 10-20 cm soil depth. The significant increase of WHC at lower slope position for 0-10 cm and 10-20 cm soil depths can be attributed to accumulation of SOM to the lower slope position. At 0-10 cm and 10-20 cm soil depths, lower slope position consists of clay soil texture which can also be a reason of high-water holding capacity at lower slope position due to the fact that smaller clay particles, which makes up the majority of soil texture, have a larger surface area and a higher water holding capacity, thus more easily able to hold water (Christina, 2017). In contrast, at summit slope position soil texture is more sandy clay which can be the reason of lower WHC, due to the higher particle size of sandy soil, which results in a reduced surface area and a low water holding capacity (Christina, 2017).

5.1.7 Final infiltration rate (IR) and Cumulative infiltration (CI)

A significant management and slope position interaction effect is observed on final IR (Figure 11a). However, the significant difference between the two management systems is observed at lower and middle slopes. Similarly, a significant interaction effect between slope position and management is observed on CI (Figure 11b). Summit slope of CA site is associated with the higher CI (54.23 cm) compared to NG site (48.01). This can be due to the covered soil at both study sites. At the CA site the soil is covered with crop residues and at NG site is covered with grasses which results in increased final infiltration rate. This observation may be due to undisturbed soil at NG site which build strong soil structure which can hold high volume of surface water.

The results suggested that the relationship between conservation agriculture and final IR and CI depends on the slope position, and it is also observed that IR rate increases with slope gradient. However, the finding of this study is different from the finding of Fox et al., (1997) who found a decrease in ultimate infiltration rate as the slope angle increases. Moreover, the summit slope position had higher final IR and CI. The higher IR at summit slope position can be due to coarse-grained texture of the soil as summit slope position has the highest percent of sand compared to other slopes and it is composed of sandy loam soil texture.

Chapter 6

6.1 Conclusion and recommendation

The current study investigates the effect of conservation agriculture and slope position on selected soil properties of Vertisol in the Limpopo province of Tshivhilwi. Conservation agriculture and slope position interaction in this research resulted in significantly higher BD, SOC, EC, AS, vf and WHC but had no effect on BD middle slope and summit slope positions at 0-10 cm, SOC summit and lower slope positions at 10-20 cm soil depth, EC summit slope at 0-10 cm, vf at summit and middle slope at 10-20 cm soil depth and WHC lower slope lower slope position at 10-20 cm soil depth. Conservation agriculture and slope positions had an influence on IR and CI, but conservation agriculture and slope positions had no effect on IR at summit slope.

According to the findings of this study, practicing conservation agriculture in various slope positions could be recommended to improve soil properties (bulk density, soil organic carbon, soil electrical conductivity, aggregate stability, total soil porosity, water holding capacity and infiltration rate) of a Vertisol. It is also suggested that in order to obtain a significant influence results of conservation agriculture and slope position interaction similar long-term investigations should be carried out in the future. Practicing conservation agriculture following all three principles could be recommended at any slope position. Additionally, the current investigation amply shown that to improve soil quality in different slope position conservation agriculture is essential.

7. References

Abdullah, M. Rafay, M. Hussain, T. Ahmad, H. Tahir, U. Rasheed, F. Ruby, T. and Khalil, S. 2017. Nutritive potential and palatability preference of browse foliage by livestock in arid rangelands of Cholistan desert (Pakistan). Journal Animal, Plants Science. 27 (5): 1656-1664

Adviento-Borbe, M.A.A. Doran, J.W. Dryber, R.A. and Doberman, A. 2006. Soil electrical conductivity and water content affect nitrogen oxide and carbon dioxide emissions in intensively management soil infiltration and drainage. Journal of Environmental Quality. 35: 1999-2000.

Alves, M.D. Schwamborn, R. Borges, C.G. Miriam Marmontel, M. Costa, A.F. Schettini, C.A. and Elisabeth de Araújo, M. 2013. Aerial survey of manatees, dolphins and sea turtles off northeastern Brazil: Correlations with coastal features and human activities. Biological Conservation. 161: 91-100.

Amezketa, E. 1999. Soil Aggregate Stability: A Review. Journal of Sustainable Agriculture. 14: 83-151.

Aytenew, M. 2015. Effect of slope gradient on selected soil physio-chemical properties of Dawja watershed in Enebse Sar Midir District, Amhara national regional state. American Journal of Scientific and Industrial Research. 6(4): 74-81.

Black, G.R. and Hartge, K.H. 1986. Bulk density. Methods of soil analysis, part 1- physical and mineralogical methods. American Society of Agronomy Soil Science Society of America, Madison. 363-382.

Bouyoucos, G.J.1962. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal 53: 464-465.

Bronick, C.J. and Lal, R. 2005. Soil structure and management: a review. Geoderma. 124: 3-22.

Chivenge, P. Murwira, H. Giller, K. Mapfumo, P. and Six, J. 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil and Tillage Research, 94(2): 328-337.

Christina M. Nouvellon Y. Laclau Jose J. and Maire G. 2017. Importance of deep-water uptake in tropical eucalypt forest. Functional Ecology 31: 509–519

Clay, D.C. Byiringiro, F.U Kangasniemi, J. Reardon, T. and Tardif-Douglin, D. 1996. Promoting food security in Rwanda through sustainable agricultural productivity: Michigan State University, Department of Agricultural, Food and Resource Economics.

D'Haene, K. Sleutel, S. De Neve, S. Gabriels, D. and Hofman, G. 2008. The effect of reduced tillage agriculture on carbon dynamics in silt loam soils. Springer Science and Business Media B.V. Nutrition Cycle Agroecosystem. 84:249-265. ISSN: 10705-008-9240-9.

Esu, I. E. Akpan-Idiok, A.U. and Eyong, M.O. 2018. Characterization and classification of soils along a typical Hillslope in Afikpo Area of Ebonyi State, Nigeria. Nigerian Journal of Soil and Environment. 8: 1-6.

Evanylo, G. and Mcguinn, R. 2008. Agricultural management practices and soil quality: Measuring, assessing and company laboratory and field test kit Indicators of Soil Quality Attributes. Virginia Cooperative Extension. 114: 452-400.

FAO (Food and Agriculture Organization of the United Nations). 2007. Conservation agriculture. Available at http://www.fao.org/ ag/ca/ [accessed August 2016].

FAO. 2019. Conservation Agriculture. Training guide for extension agents and farmers in Eastern Europe and Central Asia. ISBN 978-92-5-131456-2.122

Farmanullah, K. Hayat, Z. Muhammad, R. Prof. Dr. Zahir, S. and Muhammad, H. 2013. Effect of slope position on physico-chemical properties of eroded soil. soil and Enviroment. 31: 22-28.

Fox, D.M. Bryan, R.B. and Price, A.G. 1997. The influence of slope angle on final infiltration rate for interrill conditions, Geoderma, Volume 80, Issues 1–2, Pages 181-194,

Franzluebbe, A.J. Hons, F.M. and Zuberer, D.A. 1996. Alteration in canola residue composition during decomposition. Soil Biology, Biochemistry. 28: 1289-1295.

Giller, K.E. Witter, E. Corbeels, M. Nyamagara, J. and Tittonell, P. 2017. Conservation agriculture and smallholder farming in Africa. Field Crops Research, 114(1): 23-34.

Govaerts, B. Sayre, K.D. Goudeseune, B. De Corte, P. and Deckers, J. 2009. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Tillage. 103: 222-230.

Haghnazari, F. Shahgholi, H. and Feizi, M. 2015. Factores affecting the infiltration of Agriculture soil. International journal of Agronomy and Agriculture research. 6(5): 21-35 ISSN:2223 – 7054.

Hatfield, J.L., Sauer, T.J. and Prueger, J.H .2001. Managing soils to achieve greater water use efficiency. Agronomy Journal, 93(2): 271-280.

Horn, R. Taubner, H. Wuttke, M. and Baumgartl, T. 1994. Soil physical properties related to soil structure. Soil and Tillage Research. 30(2): 187-216

Hossein, R. Ali Asghar, J. Ahmad, A. Farzin, S. and Khalil, V.K. 2015. Effect of Slope Position on Soil Properties and Types Along an Elevation Gradient of Arasbaran Forest, Iran.

International Journal on Advanced Science, Engineering and Information Technology. 5. 449.

Hulugalle, N.R. Weaver, T.B. and Finlay, L.A. 1999. Residual effects of cotton-based crop rotation on soil properties of irrigated Vertisols in central- western and north-western. New south Wales. Australian Journal of Soil Research. 44: 467-477.

Indoria, K.A. Sharma, S.L. and Reddy, K.S. Hydraulic properties of soil under warming climate. Climate Change and Soil Interactions, Elsevier, 2020, 473-508.

Jagadamma, S. Essington, M.E. Xu, S. and Yin, X. 2019. Total and Active Soil Organic Carbon from Long-term Agricultural Management Practices in West Tennessee. Agricultural & Environmental Letters, 4: 180062.

Kassam, A. Friedrich, T. Shaxson, F. and Pretty, J. 2020. The spread of conservation agriculture. International Journal of Agricultural Sustainability, 7(4): 292-320.

Kay, B.D. and Vanden Bygaart, A.J. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil and Tillage Research. 66: 107-118.

Kemper, W.D. and Rosenau, R.C. 1986. Aggregate stability and size distribution. In Methods of soil analysis. Part 1 Physical and mineralogical method. 123: 425-442.

Khan, F. Hayat, Z. Ahmad, W. Ramzan, M. Shah, Z. Sharif, M. Mian, A. and Hanif, M. 2013. Effect of slope position on physio-chemical properties of eroded soil. Soil Environment 32(1): 22-28

Kumar, V. Kumar, M. Singh, S.K. and Jat, R.K. 2018: impact of conservation agriculture on soil physical properties. The Journal of Animal and Plant Science 28: 1432-140.

Laker M.C. 2004. Advances in soil erosion, conservation, land suitability evaluation and land use planning research in South Africa, 1978–2003. South African Journal of Plant and Soil 21: 345–368

Lal R (2004). Soil carbon sequestration impacts on global climate change and food security.

Mahanty, A. Mishra, P.K. Roul, S.N. and Panigahi, K.K. 2015. Influence of CA production system on soil organic carbon bulk density and water stable aggregates in a tropical rainfed ecosystem. Ecosystem Environment and Conservation. 21(4): 111-114. ISSN 0971-765x.

Maryam, K. Farshid, N., Ahmad, N and Karimian, M. 2011. The Effects of Slope Position on Soil Biological Properties in an Eroded Toposequence', Arid Land Research and Management, 25: 3, 308-312.

McGarry, D. 1988. Quantification of the effects of zero and mechanical tillage on vertisol by using shrinkage curve indexes. Australia. Journal of Soil Science Research. 26: 537-542.

McKenzie, N. Coughlan, K. and Cresswell, H. 2002. Soil physical measurement and interpretation for land evaluation. CSIRO publishing. Collingwood.

Mloza-Banda, H.R. Makwiza, C.N. and Mloza-Banda, M.L. 2015. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. Journal of Arid Environments. 127: 7-16.

Muchobi, J. Lungu, O.L. and Mweetwa, A.M. 2014. Conservation agriculture in Zambia: effect on selected soil properties and biological nitrogen fixation in soya beans. Sustainable Agriculture Research. 3(3): 28-36. ISSN 1927-050X.

Mustafa, A. Minggang, X. Shah, S.A. Abrar, M.A. Nan, S. Baoren, W. Zejiang, C. Qudsia Saeed, Q. Naveed, M. Mehmood, K. and Núñez-Delgado, A. 2020. Soil aggregation and soil aggregate stability regulate organic carbon and nitrogen storage in a red soil of southern China, Journal of Environmental Management, 270: 110894

Musukwa, G. 2017. Effect of conservation agriculture on physical quality of soil from medium rainfall areas of Zambia. Vrije Universiteit Brussel. Ghent University.

Nelson, D.W. and Sommer, L.E. (1982) Total Carbon, Organic Carbon and Organic Matter. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Edition. ASA-SSSA, Madison, 595-579.

Ngwira, A. Johnsen, F. Aune, J. Mekur, M. and Thierfelder, C.2013. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. Journal of Soil and Water Conservation. 69.:107-119

Nyamangara, J. Chikowe, R. Rusinambodzi, L. and. Mazvimavi, K. 2015. Conservation Agriculture in Southern Africa. International Crops Research Institution for the Semi-Arid Tropics, Matopos Research Station, Bulawayo Zimbabwe.

Oku, E. and Aiyelari, A. (2011) Predictability of Philip and Kostiakov Infiltration Model under Inceptisols in the Humid Forest Zone, Nigeria. Kasetsart Journal (Natural Science), 45: 594-602.

Paliwal, A. Singh, V.P. Guru, S.K. Pratap, T. Singh, S.P. Chandra, S. and Kumar, R. 2017. Soil physical properties as influenced by different conservation agriculture practice in rice-wheat system. International Journal of Chemical Studies. 5(4): 757-761. ISSN-2349-8528.

Passioura, J.B.1991. Soil structure and plant growth. Australian Journal of Soil Research. 29: 10.

Pathak, P. Suhas, P.W. and Sudi, R. 2011. Long-term effect of management system on crop yield and soil physical properties of semi-arid tropics of vertisols. Agricultural Science 2(4): 435-442.

Pierson, F.B. and Muila, D.J. 1990. Aggregate stability in the Palouse region of Washington. effect of landscape position. Soil Science Society of American Journal, 5: 1407-1412.

Plaster, EJ. 2013. Soil science and management. Delmar Cengage learning. 3(2): 330-449.

Rai, V. Pramanik, P. Aggarwai, P. Krishnan, P. and Bhattacharyya, R. 2018. Effect of conservation agriculture on soil physical health. International Journal of Microbiology and Applied Sciences. 7(2): 373-389. ISSN 2319-7706.

Rezaei, H. Asghar-Jafarzadeh, A. Alijanpour, A. and Kamran, K.V. 2015. Effect of slope position on soil properties and type along an elevation gradient. University of Tabriz. 5(6). 449.

Rhoades, J.D. 1982. Cation exchange capacity. In: Methods of soil analysis. Part 2. Chemical and Microbiological Properties (A.L. Page, R.H. Miller and D.R. Keeney), (Eds.) American Society of Agronomy, Inc. Soil Science Society of America. Inc. Madison, Wisconsin. 149-157.

Rillig, M. Muller, L. and Lehmann, A. 2017. Soil aggregates as massively concurrent evolutionary incubators. Multidisciplinary Journal of Microbial Ecology.11: 1943-1948.

Russel, J.A. 1967. River plains and seacoasts. Berkeley University of California Press.

Sasal, M. C., Andriulo, A. E., and Taboada, M. A. 2006. Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinian Pampas. Soil Tillage. 87: 9-18.

Schwyter, A.R and Vaughan K.L. 2021. Introduction to soil science laboratory manual. Open Education Resources, 5: 23-25.

Shaxson, T.F. Barber, R.G. 2003. Optimizing Soil Moisture for Plant Production: The Significance of Soil Porosity. FAO Soils Bulletin 79, Rome, Italy, 1–107.

Sisti, C.P.J. dos Santos, H.P Kohhann, R. Alves, B.J.R Urquiaga, S. and Boddey, R.M. 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil & Tillage Research, 76: 39-58.

Smith HJ, Kruger E, Knot J, and Blignaut J. 2016. Conservation agriculture in South Africa: lessons from case studies. In: Kassam A, Mkomwa S, Friedrich T (eds), Conservation agriculture for Africa: building resilient farming systems in a changing climate. Wallingford: CAB International. 214–245.

SSSA. 1997. Glossary of soil science terms. Soil Science Society of America.

Suryawanshi, A. Rai H.K, Mitra N.G and Upadhyay S.D. 2018. Appraisal of changes in bulk density and nitrogen content of a vertisol as affected by land use practices and depth. Journal of pharmacognosy and phytochemistry.7(2): 2080-2083.

Swanepoel, C.M. van der Laan M, Weepener H.L. du Preez C.C and Annandale J.G. 2016. Review and meta-analysis of organic matter in cultivated soils in southern Africa. Nutrient Cycling in Agroecosystems 104: 107–123.

Tangyuan, N. Bin, H. Shenzhong, T. and Zenggia, L. 2009. Effect of conventional tillage on soil porosity in maize-wheat cropping system. China Agricultural University. 10(2): 11-15.

The Non-affiliated Soil Analysis Work Committee. 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes. Pretoria: Soil Science Society of South Africa.

Thierfelder, C. Chivenge, P. and Mupangwa, W. 2017. How climate-smart is conservation agriculture (CA)? its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. Food Security. 9: 537–560.

Thomas, A. Ofosu, A.E. Emaanual, A. De-graft, A. Ayine, A.G. Asare, A. and Alexander A. 2020. Comparison and estimation of four infiltration models. Department of Mechanical and Manufacturing Engineering, University of Energy and Natural Resources, Sunyani, Ghana. 10(2): 1-13.

Turner, E.R. (2006) Comparison of Infiltration Equations and Their Field Validation with Rainfall Simulation. PhD Thesis, University of Maryland, Baltimore, MD.

Valenzuela, H. 2020. The use of crop residues on the farm. Sustainable Agriculture Newsletter. University of Hawaii Cooperative. Extension Service. Winter 2020.

Virmani, S.M. Sahrawat, K.L. and Burford, J.R. 2000. Physical and chemical properties of vertisol and their management. International Crop Research Institute for Semi-Arid Tropics, Tatachura Pradesh India. Journal of Geoscience and Environment Protection.101: 306-310.

Walkley, A., 1947. A critical examination of a rapid method for determining organic carbon in soils effect of variations in digestion conditions and of inorganic soil constituents. Soil Science, 63(4): 251-264.

Wang, Q.J. Lu, C.Y. Li, H.W. He, J. Sarker, K.K. Rasaily, R.G. Liang, Z.H. Qiao, X.D. Li, H. and McHugh, A.D. 2014. The effects of no-tillage with subsoiling on soil properties and maize yield: 12-year experiment on alkaline soils of Northeast China. Soil & Tillage Research. 137: 43-49.

West, T.O and Post, W.M. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Science. Journal. 66:1930-1946.

Zhang, Z. Qiang, H. Allen, D. Jin He, M. Li, H. Wang, Q. Lu, Z. 2015. Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China. Soil and Tillage Research.156: 173-181.

8. Appendices

8.1 Appendix A: Means of BD, OC, EC, AS, Vf and WHC as affected by conservation agriculture and slope position from 0-10cm depth.

Treatment	(g/cm3) BD	(%) SOC	(dS/m) EC	(g/g) AS	(v/v) vf	(mm/cm) WHC
Management						
CA	0.81b	1.06a	90.53a	0.69a	0.73a	12.50a
NG	1.05a	0.93b	48.75b	0.51b	0.55b	11.76a
SED	0.03	0.06	4.58	0.05	0.02	0.49
Slope position						
1. Lower	0.89b	1.10a	63.63a	0.83a	0.67a	13.54a
2. Middle	0.92b	1.02b	74.40a	0.68b	0.66ab	13.53a
3. Summit	1.04a	0.86c	70.88a	0.56c	0.60b	9.32b
SED	0.04	5.61	5.61	0.04	0.03	0.60
P value						
Management	***	*	***	**	***	ns
Slope	**	**	ns	*	*	***
Management x slope	**	***	**	*	*	**
CV	10.59	11.59	25.48	18.29	14.70	15.62

ns = not significant; * = significant at P<0.05; ** = significant at P<0.01; *** = significant at P<0.001. Different letter in the column represents significant difference

8.2 Appendix B: Means of BD, OC, EC, AS, Vf and WHC as affected by conservation agriculture and slope position at 10-20cm depth.

Treatment	**BD (g/cm3)**	**SOC (%)**	**EC (dS/m)**	**AS (g/g)**	**Vf (v/v)**	**WHC (mm/cm)**
Management						
CA	0.81b	1.13a	101.41a	0.68a	0.72a	10.48b
NG	1.10a	0.96b	47.87b	0.56b	0.61b	12.39a
SED	0.02	0.05	4.61	0.07	8.46	0.49
Slope position						
1. Lower	0.87b	1.05a	88.91a	0.63a	0.69a	13.47a
2. Middle	0.95a	1.08a	74.24b	0.54a	0.65b	11.08b
3. Summit	0.97a	1.04a	60.76c	0.40b	0.64b	9.95c
SED	0.03	0.56	5.64	0.06	0.01	0.59
P value						
Management	***	**	***	**	***	***
Slope	***	ns	***	*	***	***
Management x slope	***	***	*	*	***	***
CV	8.80	16.17	23.90	18.05	4.95	16.46

ns = not significant; * = significant at P<0.05; ** = significant at P<0.01; *** = significant at P<0.001. Different letter in the column represents significant difference

Appendix C. Means of final Infiltration rate (cm/min) and cumulative infiltration as affected by conservation agriculture and slope position of vertisol at Tshivhilwi.

Treatment	**(cm/hour) (IR)**	**(cm) (CI)**
Management		
CA	9.17a	47.79a
NG	9.10a	54.31b
SED	1.15	3.11
Slope position		
1. Lower	7.46b	40.54b
2. Middle	8.45ab	48.53ab
3. Summit	11.50a	54.23a
SED	1.62	4.39
P Value		
Management	ns	**
Slope	*	**
Management * slope	*	**
CV	86.97	83.31

ns = not significant; * = significant at P<0.05; ** = significant at P<0.01. Different letter in the column represents significant difference