Effects of tillage and mulching on selected soil properties, growth and yield of sunflower (*Helianthus annuus* L.)

by

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Declaration

I, Selolo Koena Revonia (18013548), hereby declare that this dissertation for Master of Science in Agriculture (Soil Science) at the University of Venda hereby submitted by me, has not been submitted previously for a degree at this university or any other university, that it is my own work in design and in execution, and that all reference materials contained herein have been duly acknowledged.

Signature: Date: 02/06/2021

Selolo K.R. (Student)

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Dedication

I would like to dedicate this dissertation to my parents, Phuti Sylvia Selolo and Moabelo Ambros Selolo, my son, Molebogeng and his father, Mosima Antony Magwai and my siblings, Respector, Phumzile, Sidney, Mumsy, Refilwe and Thabang for their support, unconditional love and understanding.

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List of acronyms

Acronym	Description
AI	Aridity index
ANOVA	Analysis of Variance
ARC	Agricultural Research Council
AS	Aggregate stability
BD	Bulk density
BFAP	Bureau for Food and Agricultural Policy
CEC	Cation exchange capacity
CI	Cumulative infiltration
CT	Conventional tillage
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DAP	Days after planting
EC	Electrical conductivity
FBS	Flower bud stage
FS	Flowering stage
HMS	Harvest maturity stage
IR	Infiltration rate
LA	Leaf area
LAI	Leaf area index
LSD	Least significant differences
m	Mass
MT	Minimum tillage
ns	Not significant at $P<0.05$

NT	No-tillage
SAGL	South African Grain Laboratory
SOC	Soil organic carbon
SPSS	Statistical package for the social science
SWC	Soil water content
T_{max}	Maximum temperature
T_{min}	Minimum temperature
UNESCO	United Nations Educational, Scientific and Cultural Organization
V	Volume

List of symbols

Symbol	Description
*	Significant at $P<0.05$
***	Significant at $P<0.001$
μ	Overall mean
Ca	Calcium
I	Treatment
K	Potassium
Mg	Magnesium
Na	Sodium
NaOH	Sodium hydroxide
Ѳg	Gravimetric water content
Y	Observation of the treatment
ε	Random error

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Abstract

Excessive and unnecessary tillage without residue retention can degrade the soil's physical quality, decrease soil organic carbon contents and crop yields. Although the benefits of improved tillage methods and mulching have been reported in literature, little information is available on South Africa and more so on highly weathered soils of the Limpopo province.

A study was conducted under dryland conditions at the University of Venda experimental farm, Limpopo province, South Africa. The aim of the study was to determine the effects of tillage and mulching on selected soil properties, growth and yield of sunflower (*Helianthus annuus* L.). The experiment was laid out in a split plot design with three replications. The experiment was conducted during the 2018/19 and 2019/20 cropping seasons. Treatments consisted of two (2) tillage methods (conventional and minimum tillage) and three (3) levels of avocado leaf mulch (0, 6 and 12 t/ha). The following soil properties were determined: soil organic carbon (SOC), soil water content (SWC), bulk density (BD), infiltration rate (IR), cumulative infiltration (CI) and aggregate stability (AS). Sunflower plant parameters including plant height, leaf area index, dry matter at flowering stage (FS), total biomass at harvest maturity stage (HMS), head diameter, head dry weight, seed weight and grain yield were determined.

Minimum tillage resulted in significantly higher SOC, final IR and AS than conventional tillage. Conventional tillage outperformed the minimum tillage with respect to SWC and CI in both seasons. Minimum tillage recorded significantly higher plant height, LAI, head diameter, head dry weight, seed weight and grain yield than conventional tillage. Tillage had no effect on BD, dry matter at FS and total biomass at HMS in both seasons. Avocado leaf mulch application influenced SWC, CI and AS, but had no effect on SOC, BD, final IR, sunflower growth and grain yields. The 6 t/ha and 12 t/ha mulch treatments had significantly higher SWC, CI and AS than no-mulch treatment. Significant interactions between tillage and mulch rate observed on SOC at 42 days after planting (DAP), final IR, CI and AS indicated that the differences in SOC, final IR, CI and AS in the two tillage practices can be explained, in part, by the differences in how the two tillage practices react to different levels of avocado leaf mulch. The results suggested that tillage and mulching could improve sunflower crop yields, soil organic carbon, soil water content, infiltration rate and aggregate stability under the experimental conditions.

Keywords: *tillage, mulching, water scarcity, crop yields, soil properties*

1. Introduction

1.1 General Background

Agriculture plays a major role in providing food security, assisting in the creation of jobs and in the alleviation of poverty (Lopez, 2002). Due to the harsh environmental conditions found in South Africa, dryland crop production with high yields has been difficult to attain (Bennie and Hensley, 2001). In Sub-Saharan Africa (e.g. South Africa, Kenya, Nigeria), rain-fed agriculture is the dominant source of food production practice by most smallholder farmers (Bennie and Hensley, 2001; Cooper *et al.*, 2008). However, due to the frequent occurrence of droughts and dry spells, water has become a limiting factor during crop growing seasons, threatening smallholder farmers' food security (Mafongoya *et al.*, 2016).

Limpopo province is within the inland regions of South Africa which has been described as a water scarce region experiencing droughts in every eight (8) years (Thomas, 2003). The province was among the provinces declared drought-stricken in the years 1982 to 2009 (Maponya and Mpandeli, 2012). It receives an average annual rainfall ranging between 300 and 600 mm and therefore, water is the most limiting resource in the province. The smallholder farms are located mostly in the former homeland areas and they cover approximately 30% of the provincial land surface area. Farming under the smallholder systems is characterized by low levels of production technology and small size of farm holding of approximately 1.5 hectares per farmer; with production primarily for subsistence and little marketable surplus (Oni *et al.*, 2003).

Common field crops such as maize, wheat, sorghum, groundnut, cowpea and sunflower seed occupy a larger area of planted farmlands in the Limpopo province (Thomas, 2003). Sunflower (*Helianthus annuus* L.) is a drought tolerant crop and it is planted from the beginning of November to the end of December within the inland regions of South Africa (SAGL, 2016). Sunflower production is relatively limited and it is almost entirely cultivated by smallholder farmers in the Limpopo province. In the year 2002, the estimated total output was 526 tons of sunflower seed, which was the lowest output obtained within the cropping season (Thomas, 2003). Sunflower seed production was 90 000 tons in the 2009 cropping season (DAFF, 2011). In the 2010 to 2015 cropping seasons, the estimated output of sunflower decreased from about 99 000 tons to 59 900 tons (SAGL, 2016). The area dedicated to sunflower was 89 100 ha in the 2013/2014 growing season and reduced to 81 300 ha in the 2014/2015 growing season in the Limpopo province. A decrease in the area planted under dryland conditions led to varying outputs, where 74 250 tons and 59 900 tons of the crop were obtained in the 2013/2014 and 2014/2015 growing seasons, respectively (SAGL, 2016).

Crop production in the smallholder sector is not only limited by water scarcity alone, but also by long periods of drought and dry spells, soil degradation and poor soil fertility. Water scarcity, poor soil fertility, soil degradation and frequent occurrence of drought and dry spells contribute to high risk of total crop failure associated with the arid and semi-arid environments (Bennie and Hensley, 2001; Kundhlande *et al.*, 2004). Smallholder farmers continue to experience low crop yields in the province as a result of poor soil management practices, poor soil fertility, water shortage and degraded soil quality. The situation is more aggravated by high atmospheric temperatures, soil water evaporation losses and monoculture system of staple food crops such as maize and sorghum (Bennie and Hensley, 2001; Ramaru *et al.*, 2000). Soil erosion, poor soil type, lack of soil residue coverage, the use of excessive and unnecessary tillage greatly contribute to poor soil productivity and fertility (Ramaru *et al.*, 2000; Ahmad *et al.*, 1996; Ogle *et al.*, 2003).

Numerous smallholder farmers in the Limpopo province depend on conventional tillage methods in preparation for sowing or transplanting seasonal or annual crops. Tillage may be effective at controlling weeds, destroying pests and their breeding places, removing the hard pan and increasing soil depth, soil aeration and making the soil capable for absorbing rain water, creating soil conditions suitable for crop growth, providing adequate contact between the seed and the soil in order to permit water flow to seed and seedling and uniformly mixing manure and fertilizer in the soil (Leij *et al.*, 2002). However, continuous and excessive tillage operations may ruin soil structure, contribute to high soil moisture losses and increase the incident of soil erosion, disrupt the lifecycle of beneficial soil organisms such as earthworms which help in the decomposition of residues, decrease soil organic carbon and increase soil compaction (Ahmad *et al.*, 1996; Ogle *et al.*, 2003).

Conservation tillage (minimum tillage, ridge tillage, zero tillage and mulch tillage) methods are reported to have favourable benefits as compared to conventional tillage method. Conservation tillage methods are favourable for reducing soil compaction and soil erosion since the topsoil is always protected and less or not tilled, conserving soil water since residues are left on the soil surface which reduces water to evaporate, protecting impacts from rain and wind, improving soil condition with increased organic matter content and reduces overall production cost (Six *et al.*, 2000; McCarthy *et al.*, 1995; Erenstein, 2002).

Mulches are used in crop production practices to improve the physical and chemical properties of the soil. Mulching practices are reported to improve water infiltration rate during intense rains (Glab and Kulig, 2008), reduce soil evaporation (Bennie and Hensley, 2001), moderates soil temperature (Sarkar *et al.*, 2007), and reduces runoff and soil erosion (Lal *et al.*, 1990; Erenstein, 2002). The application of crop residue mulches has also been reported to increase the content of organic carbon in the soil (Havlin *et al.*, 1990) and improving soil water content (Yang *et al.*, 2018).

Soil tillage and residue mulching have greater influence on soil properties, crop growth and yield (Kahlon *et al.*, 2013; Li *et al.*, 2018). A combination of soil tillage and the application of mulches have been reported to increase crop yields, soil organic carbon, moisture content, aggregate stability and infiltration rate, reduce soil evaporation, and soil bulk density and moderates soil temperature (Salem *et al.*, 2015; Sarkar *et al.*, 2007; Bennnie and Hensley, 2001; Yang *et al.*, 2018). A number of studies have been conducted on the effects of tillage methods and mulching on soil bulk density, soil water infiltration, soil organic carbon content, soil evaporation, soil water content, aggregate stability, soil temperature and on the growth and yield of crops around the world and in South Africa (Pal and Mahajan, 2017; Yang *et al.*, 2018; Bennie and Hensley, 2001; Salem *et al.*, 2015).

Pal and Mahajan (2017) reported a short term increase in steviol glycoside yield and soil organic carbon content under a combination of tillage systems and mulching treatments in the study conducted in India. Yang *et al.* (2018) evaluated the effects of tillage and mulching measures on soil moisture and temperature, photosynthetic characteristics and yield of winter wheat and the results showed that straw coverage and film mulching measures under the conventional tillage and no-tillage methods increased soil moisture content and increased soil temperature at tillering stage. The yield of winter wheat also increased by 6.4% - 9.3% in straw coverage and film mulching under the conventional tillage. Bennie and Hensley (2001) reported high soil water evaporation on conventionally tilled soils as compared to soils with more than 30% surface residue coverage in the study conducted in South Africa. Li *et al.* (2016) reported an increase in the yield of winter wheat, better soil water status and root growth, and enhanced water use efficiency under tillage practices and straw mulching. Kahlon *et al.* (2013) reported greater water stable aggregates under no-tillage system compared to plow tillage. Salem *et al.* (2015) reported lowest soil temperature under zero tillage plots with considerable amount of surface residue and highest soil temperature under conventional tillage plots with less residue cover. However, results from such studies are site and crop specific. The results showed variations in soil bulk density under zero tillage, reservoir tillage, minimum tillage and conventional tillage.

The aim of the study was to investigate the effects of two tillage methods (conventional tillage and minimum tillage) and mulching (avocado leaf mulch) on selected soil properties, growth and grain yield of sunflower under rainfed conditions in Limpopo province.

1.2 Problem statement

There is a general reduction of potential crop yields in SA (DAFF, 2012). Limpopo province like other provinces in South Africa has also experienced yield reductions in terms of maize, wheat, soybean, and sunflower crops. Common droughts and prolonged dry spells limit the availability of water during crop growing seasons thus threatening the smallholder farmers' livelihoods (Mafongoya *et al.*, 2016; Walker and Schulze, 2008). Water scarcity, which is one prime concern in South African agriculture (Thomas, 2003) and the loss of soil water through evaporation (Bennie and Hensley, 2001) has further aggravated the low agricultural crop productivity in the Limpopo province.

The traditional conventional tillage practices are used by most smallholder farmers in the province, however, the excessive and unnecessary tillage without residue retention can degrade soil's physical quality, decrease soil organic carbon contents and crop yields (Dao, 1996). Although the benefits of improved tillage methods and mulching have been reported in literature, little information is available on South Africa and more so on highly weathered soils of the Limpopo province. Therefore, this study will investigate effects of tillage methods (conventional and minimum tillage) and soil surface coverage (mulches) on selected soil properties and growth and yield of sunflower.

1.3 Justification of the study

The successful evaluation of a suitable and protective tillage method (tillage-mulching method) through the evaluation of effects of tillage and mulches could improve sunflower crop yields, food security, better nutrition and income to farmers and soil physical and chemical quality in the Limpopo province. The information obtained through this study will also serve as baseline data for more research on tillage and mulches worldwide. In addition, agricultural advisors could utilize the information from such a study to give appropriate advice to farmers.

1.4 Objectives of the study

1.4.1 General objective

To determine the effects of tillage and mulching on selected soil properties and growth and yield of sunflower.

1.4.2 Specific objectives

To determine the effects of two tillage methods (conventional and minimum) and avocado leaf mulch on:

a) Selected soil properties (soil organic carbon, soil water content, bulk density, infiltration rate and aggregate stability).

b) Sunflower height, leaf area index, dry matter at flowering stage, total biomass at harvest maturity stage, sunflower head diameter, head dry weight, seed weight and grain yield.

1.5 Hypotheses

Tillage methods (conventional and minimum tillage) and avocado leaf mulch:

a) Will have no effect on selected soil properties (soil organic carbon, soil water content, bulk density, infiltration rate and aggregate stability).

b) Will not affect the height, leaf area index, dry matter at flowering stage, total biomass at harvest maturity stage, head diameter, head dry weight, seed weight and grain yield of sunflower.

2. Literature review

2.1 Tillage definition, importance and methods

Tillage refers to the overturning, digging and stirring of soil by mechanical or manual means in preparation of the land for agricultural purposes (Conant *et al.*, 2007). It is therefore, regarded as a method of soil preparation for seedbed grounding, sowing of seeds, transplanting seedlings and for crop growth. The general objectives of soil tillage are to prepare a good seedbed which helps the germination of seeds, effectively control weeds, destroy pests and their breeding places, remove the hard pan and to increase the soil depth, aerate the soil, make the soil capable of absorbing rain water, create soil conditions suitable for crop growth, provide adequate contact between the seed and the soil in order to permit water flow to seed and seedling and lastly to uniformly mix manure and fertilizer in the soil (Leij *et al.*, 2002).

The methods of tillage used by farmers in agriculture are conventional tillage, minimum tillage, ridge tillage, zero tillage and mulch tillage. Conventional tillage is a method in the intensive tillage system while minimum, ridge, zero and mulch tillage's are methods in a conservation tillage system (Haruna *et al.*, 2017; Ogle *et al.*, 2003). Intensive tillage leaves less than 15% crop residue cover or less than 560 kg/ha of small grain residue on the surface (Lal *et al.*, 1990). Conventional tillage as a method of intensive tillage, involves deep cultivation of the soil using a plough (mould board, disk or chisel plough) and a finisher with a harrow, rolling basket and a cutter to prepare the field for crop production (Leij *et al.*, 2002).

The advantages of conventional tillage are to; destroy pests' shelters and disrupt their life cycles, expose pests to predators and unfavourable conditions, distribute soil nutrients, aerate the soil, control weeds and make other farm cultural practices easier to undertake. There are also disadvantages that are associated with conventional tillage. It destroys the soil cover and its structure, aggravates the frequency of soil erosion, contributes to high soil moisture losses, disrupts the lifecycle of beneficial soil organisms such as earthworms which help in the decomposition of residues and it needs more labour for the soil preparation (Ogle *et al.*, 2003).

Conservation tillage leaves at least 30% of crop residue or at least 1100 kg/ha of small grain residue on the soil surface during critical soil erosion period (Erenstein, 2002; Petersen *et al.*, 2011). Minimum tillage is a method of conservation tillage system where the soil is not turned over (West and Post, 2002), thus, the soil is manipulated to a minimal extent. Ridge tillage is a form of no-till wherein a new crop is planted on pre-formed ridges from those of the previous crop and the crop residues are left on the surface until planting time (Li *et al.*, 2017). In zero tillage, the soil is not disturbed between harvesting one crop and planting the next crop. The soil is not traditionally tilled although sticks or other planting equipment's are used to make openings for seeds. In mulch tillage, the soil is prepared in such a way that mulching materials (30% or more) are specifically left on or near the surface of the farm (Salem *et al.*, 2015).

Methods of conservation tillage have advantages and disadvantages, however, they contribute to less damage as compared to intensive tillage. The advantages include reduced soil compaction and soil erosion, conserves soil water, protects the soil from impacts of rain and wind, improves soil condition with increased organic matter content and reduces overall production costs (Six *et al.*, 2000; McCarthy *et al.*, 1995; Erenstein, 2002). The disadvantages of conservation tillage methods include increased soil pests population, weeds competing with the main crop for water and nutrients, high tendency of a carryover of insect pests and diseases from crop residues, organic matter is not evenly distributed or will be concentrated on the topsoil, the methods require some patience and one has to wait for a longer time to obtain excellent soil and also requires careful farm management practices to be successful (Erenstein, 2002; Mangalassery *et al.*, 2014).

2.1.1 Effects of tillage on selected soil properties

An understanding of the effects of different methods of tillage on soil physical properties serves as an important measure for determining soil productivity. Generally, most smallholder farmers in South Africa depend on different methods of tillage in preparation for sowing seeds or transplanting seasonal or annual crops. Many soil physical properties interact with each other, and thus, the value of one is affected by one or more of the selected parameters (Arshad and Martin, 2002). Considerable research has been conducted on the effects of different tillage systems on the physical, chemical, and biological properties of soils (Liebig *et al.*, 2004; Tarkalson *et al.*, 2006). The effects of intensive tillage (conventional tillage) and conservation tillage (minimum tillage, ridge tillage, mulch tillage, and zero or no tillage) operations on soil particle size distribution, bulk density, soil strength, mean pore-size, infiltration rate, soil water content, aggregate stability, soil temperature, soil evaporation, soil organic carbon, and saturated hydraulic conductivity was evaluated by Kilic *et al.* (2004) and Haruna *et al.* (2017), and on P (phosphorus) at different soil moisture contents were evaluated by Utset and Cit (2001), Ferrero *at al.* (2005), Ahamefule and Chinedu (2014), and Veronese Júnior *et al.* (2006). As most of the studies conducted to date have addressed changes in surface soils as a result of tillage, more information on the effect of different tillage systems on soil physical properties are limited in Limpopo province, South Africa.

2.1.2 Effects of tillage on soil organic carbon

Organic carbon is a measure of the carbon contained within soil organic matter. Soil organic carbon improves the physical, chemical and biological properties of soil. It increases the cation-exchange capacity (CEC) and water-holding capacity of sandy soil, and it contributes to the structural stability of clay soils by helping to bind particles into aggregates (Gao *et al.*, 2017). Soil organic matter, of which carbon is a major part, holds a great proportion of nutrient cations and trace elements that are important for plant growth. It prevents nutrient leaching, and is integral to the organic acids that make minerals available to plants. It also buffers soil from strong changes in pH (Pal and Mahajan, 2017). Tillage practices tend to inhibit the formation of micro-aggregates with macro-aggregates resulting in smaller differences in soil organic carbon content between the internal and external layers of the soil and in turn lowers the soil organic carbon in the bulk soil (Fan, *et al.*, 2013).

Gao *et al.* (2017) reported high contents of soil organic carbon in the external and internal layers of soil under shallow tillage and no-tillage operations as compared to conventional tillage in a study conducted in China and Belgian. A number of studies were undertaken to determine the effects of tillage on soil organic carbon content (Zhang-liu *et al.*, 2013; Zhang *et al.*, 2017). Zhang-liu *et al.* (2013) investigated soil aggregate-associated carbon under different tillage systems in the North China Plain. Higher soil organic carbon content correlated positively with the mean weight diameter of aggregates and macro-aggregate fractions in no-tillage methods while lower content of soil organic carbon was observed under conventional tillage (or moldboard plough). Similarly, Zhang *et al.* (2017) observed high levels of soil organic carbon in no-tillage operations than in continual tillage operations in a study conducted in China. There is limited research on the effect of tillage on soil organic carbon in different regions of South Africa. Therefore, this calls for a closer look at the effect of tillage on soil organic carbon, particularly in the dryland regions of the Limpopo province.

2.1.3 Effects of tillage on soil water content

Soil water content involves the amount of water contained within the soil matrix. Soil water is important for nutrient availability and transport (Sparling and West, 1989) and microbial activity (Sylvia *et al.*, 2005). Tillage methods used on the land may alter the amount of water contained in the soil. Studies on the effects of tillage on soil water content have been undertaken globally and have reported different results. Haruna *et al.* (2017) reported higher soil water content at the 0.0 and -0.4 kPa pressures for the conventional tillage (moldboard plough tillage) compared with no-till management. Schwartz *et al.* (2010) reported that soil water content decreased within the first 0 -30 cm depth of soil and even after considerable amounts of precipitation under mulch tillage as compared to untilled plots. Salem *et al.* (2015) observed soil moisture content of zero tillage being greater than that of minimum tillage and conventional tillage. The success of soil water conservation however depends upon many soil factors such as soil bulk density, porosity, soil surface sealing and crusting, surface roughness, hardpans, hydraulic conductivity, and infiltration rates as they determine the hydrological properties of soil (Strudley *et al.*, 2008).

Investigating the effect of tillage on soil water content will help determine a way to reduce soil water losses and implement effective water conservation strategies under dryland conditions.

2.1.4 Effects of tillage on bulk density

Bulk density serves as a measure of soil compaction. It is defined as the weight of dry soil in a given volume. Bulk density increases with compaction and tends to increase with depth (Freitag, 1971). An increase in soil bulk density may alter root configuration and root-soil interactions (Croretto, 1998). Kahlon *et al.* (2013) argue that no-tillage and ridge tillage can significantly lower soil bulk density at the surface layer as compared to conventional tillage operations. Other researchers (Croretto, 1998; Dao, 1996; MacVay *et al.* 2006; Shaver *et al.* 2002) also reported a reduction in soil bulk density in no-tillage operations. However, in contrast to the above mentioned studies, Salem *et al.* (2015) found soil bulk density of zero tillage > minimum tillage > reservoir tillage > conventional tillage in the upper soil layers in the study conducted in Central Spain. The lower soil bulk density in conventional tillage method was also reported by Afzalinia and Zabihi (2014), Fabrizzi *et al.* (2005), and Taser and Metinoglu (2005). There is therefore, contrasting findings on the effects of different tillage methods on soil bulk density, hence this study will put more effort on corroborating the effects of tillage methods (conventional and minimum tillage methods) on soil bulk density.

2.1.5 Effects of tillage on infiltration rate

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. When water is supplied at a rate that exceeds the infiltration capacity of the soil, it turns to produce water runoff on slopping lands or ponds on surfaces of level lands. Restricted infiltration and water ponding may result in poor soil aeration which causes considerable damage to plant roots, nutrient availability and cycling by soil organisms (de Almeida *et al.*, 2018). Tillage methods and soil disturbance activities that disrupt surface connected pores and prevent accumulation of organic matter may alter the infiltration rate of the soil. The infiltration rate of untilled plots appeared to be lower than the infiltration rate of mulch tillage in the research conducted by Schwartz *et al.* (2010). Kahlon *et al.* (2013) reported more rapid infiltration rates on plough tillage operation and slow infiltration rates on no-tillage operations. A study conducted by Lal (1997) also validates the findings of other researchers, where conventional tillage operations resulted in higher infiltration rates than no-tillage operations. More research remains to be done since there is limited information on the effects of tillage on infiltration, particularly on deep soils of Vhembe district.

2.1.6 Effects of tillage on aggregate stability

Aggregate stability serves as a measure of the ability of soil aggregates to resist degradation when subjected to external forces such as water or wind erosion, shrinking or swelling processes and tillage practices (Six *et al.*, 1998; Papadopoulos *et al.*, 2011). Soil tillage can affect the stability and formation of soil aggregates by disrupting soil structure (Zheng *et al.*, 2018). Conservation tillage (minimum tillage, no-tillage, reduced tillage) were reported to increase the stability of soil aggregates as compared to conventional tillage practices (Jacobs *et al.*, 2009; Six *et al.*, 2000). Kahlon *et al.* (2013), reported greater water stable aggregates in no-tillage system in contrast to plow tillage. There is limited information on the effects of tillage methods on soil aggregate stability, hence this study will attempt to close the gap by concentrating on tillage methods and their effects on soil aggregate stability, in deep soils in the Vhembe district, Limpopo province.

2.2 Mulch definition, importance, types and applied levels

Kindersley (2008) defines mulching as a practice of applying a protective layer of material to the soil surface. A protective covering using bark chips, straw, plastic sheeting or tree leaves placed on the ground around plants is referred to as mulch. Mulching may be applied to bare soil or around existing plants (Sarkar and Singh, 2007). The process of mulching is used in commercial crop production, subsistence farming and in gardening practices. When this process is applied correctly, it can radically improve soil productivity (Erenstein, 2002; Whitefield, 2004). Agriculture with mulch promotes plant health and better vigour, and consequently improve plant resistance to pests and diseases. Mulching also improves nutrient and water retention in the soil, encourages favourable soil microbial activity, supresses weed growth and when executed properly can significantly improve the well-being of plants and reduce maintenance as compared to bare soil culture (Kindersley, 2008; Erenstein, 2002).

There are two types of mulches which include organic and inorganic mulches (Holland, 2004). The materials used for organic mulches include sawdust and wood chips from the pruning of trees as a means of disposing bulky waste by arborists or parks; chopped or shredded leaves from deciduous trees, which drop their foliage in the fall; straws from the leftover stems of harvested grain crops; grass chopping's from mowed lawns, peat moss or sphagnum peat and compost (Gill, 2014; Milne and Brown, 1997). The inorganic mulches include rubber mulch from recycled tyre rubber; plastic sheeting of clear or black plastic where crops grow through the slits or holes in the thin plastic sheeting; stones and small chips of bricks (Yang *et al.*, 2015; Yoo-Jeong *et al.*, 2003). The use of mulching is also governed by the advantages and disadvantages of the mulching material. Some of the advantages of mulching include weed suppression, reduced evaporation, improvements in nutrient and water retention in the soil, favourable encouragement of soil microbial activity and worms, retention of moisture, prevention of soil erosion, control of weeds and addition of nutrients to the soil (Lal *et al.*, 2007). The disadvantages of mulching practices are that the cost of some materials can be a drawback to large scale mulching, some mulch are not readily available, when sawdust and wood chips are used as mulch plant nitrogen starvation may occur and heavy mulching over a period of years results in a build-up of soil over the crown area of plants (Dong *et al.*, 2018; Arora *et al.*, 2011).

The levels of organic mulches applied in agriculture differ depending on the interest of the user. A number of studies were undertaken on the application of mulches under different soil management practices and land uses (Pal and Mahajan, 2017; Jiang *et al.*, 2018; Kahlon *et al.*, 2013). Jiang *et al.* (2018) investigated soil macrofauna assemblage composition and functional groups in no-tillage with four (4) levels of corn stover mulch (0, 2.5, 5 and 7.5 t/ha of corn stover mulch) in agroecosystems in the mollisol area of northeastern China. Three (3) levels of organic mulch (0, 8 and 16 Mg/ha) were used in the study of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio by Kahlon *et al.* (2013). Furthermore, Pal and Mahajan (2017) investigated four (4) levels of pine-needle mulch (0, 5, 10 and 15 t/ha) and tillage systems on leaf biomass and yield of steviol glycoside and soil health under sub-temperate conditions. In most cases, the levels of organic mulch applied do not reach or exceed 20 t/ha.

2.2.1 Effects of mulching on selected soil properties

The use of mulching practices may alter the physical and chemical status of the soil either positively or negatively. A number of studies have been investigated on the effect of mulches on soil properties (Kahlon *et al.*, 2013; Erenstein, 2002; Gill and Jalota, 1996; Bennie and Hensley, 2001). Effects of organic and inorganic mulches on soil bulk density, penetration resistance, mean pore-size, infiltration rate, soil water content, soil evaporation, soil organic carbon and soil hydraulic conductivity have been investigated by several researchers around the world. Dong *et al.* (2018) investigated the effects of plastic film mulching and straw mulching on soil water content and soil organic carbon. In the study conducted by Tao *et al.* (2015), soil water content and water use efficiency of spring maize were investigated under straw mulch treatments in Northern Huang-Huai-Hai Valley, China. Erenstein (2002) investigated the implications of crop residue mulching on soil water conservation, infiltration of rain water and evaporation losses. Little is known about the effects of mulches on soil physical properties in the regions of the Limpopo province and South Africa as a whole. This study will, therefore, close the gap on the effects of mulches on soil properties under the region of the Vhembe district.

2.2.2 Effects of mulching on soil organic carbon.

The application of crop residue mulches tends to increase the content of organic carbon in the soil (Duiker and Lal, 1999; Havlin *et al.*, 1990; Paustian *et al.*, 1997a). The research by Pal and Mahajan (2017) showed an increase in soil organic carbon due to the application of mulches in all the cropping seasons as compared to no-mulch treatment, irrespective of the tillage systems used. Duiker and Lal (1999) investigated the effects of crop residue application on soil organic carbon and reported a linear effect of mulch application rate on soil organic carbon content. Biodegradable plastic film mulch was used under high tunnel plots and open field plots, where the results showed greater soil total organic carbon content under high tunnel plots than in open field plots (Li *et al.*, 2014). Therefore, different mulches used in the field present different outcomes in terms of soil organic carbon contents but generally favourable results are obtained.

2.2.3 Effects of mulching on soil water content

Soil moisture conservation is one of the most important contributions from mulch farming system (Mulumba and Lal, 2008). In a study conducted by Dong *et al.* (2018), soil water content was higher under plastic film mulching treatment than in straw mulching treatment and mainly changed in the upper 60 cm of the soil layer. Tao *et al.* (2015) reported that soil water content was higher in the field applied with chopped maize straw mulch than in the field of prostrate whole straw mulching. Sharma *et al.* (1990) reported residual soil moisture increase after the application of maize stalk mulch on sandy loam soils. Jordan *et al.* (2010) observed an increase in soil moisture content at field capacity with an increase in mulching rate.

2.2.4 Effects of mulching on bulk density

Considerable research has been done on the effects of mulches on soil bulk density. Mulumba and Lal (2008) found the effects of crop residue mulches on soil bulk density to be highly variable where in some cases high and low bulk density values were observed. Unger and Jones (1998) observed a decrease in soil bulk density while Bottenberg *et al.* (1999) reported an increase in bulk density and Duiker and Lal (1999) observed no effect of mulching on soil bulk density. Kahlon *et al.* (2013) highlighted a decrease in soil bulk density with increase in mulch rate from 0 – 16 Mg/ha. Soil types, climate, tillage practices, type of mulch and the intensity of other soil properties may result in the varying effects of mulching on soil bulk density (Mulumba and Lal, 2008).

2.2.5 Effects of mulching on infiltration rate

Mulching treatments are reported to have an effect on the hydrological properties of the soil. Kahlon *et al.* (2013) reported higher soil water infiltration rate with an increase in mulch rate from 0 – 16 Mg/ha under different tillage practices. Alliaume *et al.* (2017) found that soil moisture content under reduced tillage with organic residue mulch was larger than in conventional tillage with organic residue mulch mainly due to a larger infiltration rate in to the soil. Plastic mulching with holes was reported to increase rainfall infiltration as compared to the traditional flat mulching (Kader, 2016). The use of ridge plastic film mulching increased soil water infiltration by particularly channelling rain water into the furrows, reducing surface runoff and consequently increasing water use efficiency (Zegada-Lizarazu and Berliner, 2011). In contrast, Jiang *et al.* (2017) reported that the greater the amount of residual plastic mulch fragments applied, the lesser the rate and amount of water infiltration into the soil.

2.2.6 Effects of mulching on aggregate stability

Considerable research has been done on the effects of mulching on soil aggregate stability. Residue mulching is reported to improve soil aggregate stability and aggregate formation. Jordan *et al.* (2010), reported an increase in aggregate stability in wheat straw mulch treatments as compared to no-mulch treatment. Simsek *et al.* (2017), reported significantly higher aggregate stability under straw mulch plots compared to no-mulch plots. Kahlon *et al.* (2013), observed no effect of mulching on water stable aggregates among all mulch treatments. Therefore, there is contrasting findings on the effects of mulching on aggregate stability, hence this study will put more effort on corroborating the effects of mulching (avocado leaf mulch) on soil aggregate stability.

2.3 The interaction between tillage and mulching and their effects on soil properties and crop yields

Soil tillage and mulches are considered to have a strong effect on soil physical properties, crop yield and overall soil productivity (Kahlon *et al.*, 2013; Yang *et al.*, 2018; Zhang *et al.*, 2017; Li *et al.*, 2018). Numerous studies have been conducted on the effects of tillage methods and mulching on soil bulk density, soil water infiltration, soil organic carbon content, soil temperature, soil water content and on the growth and yield of crops around the world. Pal and Mahajan (2017) compared two (2) tillage operations (conventional tillage and zero tillage) with the application of different rates (0, 5, 10 and 15 t/ha) of pine needle mulch and found conventional tillage with mulching having favourable results than zero tillage with mulching. The results showed an increase in soil organic carbon content and higher leaf yield on steviol glycoside under conventional tillage with pine needle mulch than in zero tillage with pine needle mulch. *Song et al.* (2016), observed improved soil aggregate stability at 0-15 cm and 15-30 cm soil layers under zero tillage with straw mulch incorporation compared to conventional tillage with straw mulch incorporation.

The use of ridge tillage and stalk mulching decreased evapotranspiration on winter wheat planted field, increased soil moisture content, grain yield and water use efficiency of winter wheat as compared to conventional tillage with stalk mulch application (Li *et al.*, 2018). In the research conducted by Tao *et al.* (2015), subsoil tillage with chopped straw mulch increased soil water content by 2.9% and 3.0% in the years 2012 and 2013 as compared to subsoil tillage with prostrate whole straw mulch. Soil tillage and mulches have been found to increase water infiltration rate due to reduced runoff from the land surfaces.

Alliaume *et al.* (2017) obtained less runoff in the field of reduced tillage with mulching than in conventional tillage with mulching, which led to increased infiltration capacity of the soil. The interaction of tillage and mulches can reduce soil temperature oscillations within a short period of days. Salem *et al.* (2015) reported a general increase in soil temperature and yield of winter wheat under conventional tillage and straw mulching. According to Pituello *et al.* (2016), mulching effects on crop growth and yield depends on the climatic conditions of the area, soil texture and crop type. In the research conducted by Dong *et al.* (2018) in China, maize and winter wheat yields increased under both straw mulching and plastic film mulching as compared to treatments with no mulch application. Very few studies have explored the effects of combined tillage methods and mulches on soil bulk density, soil temperature, soil water content, infiltration, soil organic carbon and on the grow and yield of sunflower in the arid and semi-arid regions of SA, hence, this study will explore the combination of tillage and mulching under dryland conditions in Limpopo province.

2.4 Sunflower crop

Sunflower (*Helianthus annuus* L.) is a field crop that originated in North America most probably in 1000 BC. It was first introduced to Europe through Spain, then further spread to Russia in the 1860s. The production of sunflower spread to other countries in the world through the years and also reached South Africa (DAFF, 2010). It is an annual crop and its botanical name was derived from Greek words, ‘helios’ (sun) and ‘anthos’ (flower). The sunflower crop is erect, has broad leaves with a strong taproot and prolific lateral spread of surface roots. Stems are usually round early in the season, angular and woody later in the season, and normally unbranched (DAFF, 2010).

Sunflower leaves are phototropic and follow the sun’s rays with a lag of 120 behind the sun’s azimuth. Its total growing period ranges from 125 to 130 days. The sunflower head is made up of 1,000 to 2,000 individual flowers joined at a mutual receptacle and it is a self-pollinated plant (DAFF, 2010). Sunflower adapts relatively well to a wide variety of soil types. Sunflower cultivation has been limited to soils where the clay percentage varies between 15 and 55 %, classified as sandy loam to clay soil types. Presently, the major planting areas are in soils with a clay percentage of less than 20% (SAGL, 2016).

2.4.1 Importance of sunflower

The economic value of sunflower is mostly derived from oilcake and vegetable oil whose demand has increased by approximately 40% in the last few decades in South Africa (BFAP, 2015). Sunflower is considered an oilseed crop and it can be used as edible oil in the form of margarine, salad dressing oil and cooking oil and the seeds can also be used as snacks. Its nutritional value makes it suitable for animal and poultry feed. It is rich in protein (28 to 42 %) and other nutrients as compared to corn but lower than alfalfa. The non-dehulled or partially dehulled meal of sunflower may be supplied to ruminants, pigs and poultry as feed and sunflower silage is also suitable as animal feed (DAFF, 2010).

The industrial importance of sunflower is evidenced by its use in certain paints, varnishes and plastics due to its good semi-drying properties without colour modification associated with oils high in linolenic acid. Sunflower can be used to manufacture soaps and detergents and in the production of pesticides, surfactants, adhesives, fabric softeners, lubricants and coatings. A future high-potential use will be on diesel engines as the world is striving for a non-polluted environment (DAFF, 2010). Food crops, like sunflowers, are a promising renewable energy alternative, usually for biodiesel production (Vilvert *et al.*, 2018).

2.4.2 Sunflower production in South Africa

Sunflower is the fourth largest grain crop produced in South Africa after maize, wheat and soybean. Sunflower seed production is very suitable for South African climatic conditions as sunflower plants are drought tolerant. The deep root system of a sunflower enables the plant to perform better than other crops during dry seasons (SAGL, 2016). The production of sunflower in South Africa, is most prevalent in the summer rainfall areas and the planting starts from the beginning of November to the end of December. Out of the nine (9) provinces of South Africa, sunflower production takes place in only eight (8) provinces. The provinces such as North West, Free State, Mpumalanga, Gauteng and Limpopo are described as the major production areas of sunflower while Eastern Cape, Northern Cape and Western Cape produce very small quantities of sunflower (DAFF, 2010; DAFF, 2011; SAGL, 2016). The production of sunflower is generally concentrated in the Free State and North West Provinces, which together account for up to 79% of the national area planted to sunflower (BFAP, 2015).

Local annual production for sunflower seed ranges between 500 000 to 700 000 tons and the average yield ranges from 1.2 to 1.8 t/ha under dry land. In 2004/2005 production season, sunflower seed production contributed approximately 1.2 % to the gross value of agricultural production in South Africa (DAFF, 2010). A decrease in sunflower grain yield was observed in 2006/2007 production season. An increase in sunflower grain yield was observed in the 2007/2008 production season. The area utilized for sunflower production decreased by almost 4% from 598 950 hectares in the 2014/2015 growing season to 576 000 hectares and the yield decreased from 1.39 t/ha to 1.15 t/ha (SAGL, 2016). Therefore, the area dedicated to sunflower production has to increase in order to obtain increased sunflower yields.

2.4.3 Sunflower production in Limpopo Province

Limpopo province is endowed with abundant agricultural resources and it is one of the country's prime agricultural regions noted for the production of livestock, fruits and vegetables, cereals and tea (Oni *et al*., 2003). The province comprises of five districts; Mopani, Vhembe, Capricorn, Waterberg and Sekhukhune district. Out of the five districts, only two (Sekhukhune and Waterberg districts) participate in the production of sunflower under both commercial and smallholder farming (DAFF, 2010). In the 2014/2015 production season, sunflower yields of 0.74 t/ha under dryland farming and 2.29 t/ha under irrigated farming were obtained, making Limpopo province the third largest producer after Free State and North West provinces in South Africa (SAGL, 2016).

3. Materials and methods

3.1 Description of study site

A field experiment was conducted during the 2018/19 and 2019/20 cropping seasons under dryland conditions at the University of Venda experimental farm (22º 58’ S; 30º 26’ E). The experimental site is located in Thulamela Municipality and it is about 2 km west of Thohoyandou town in Vhembe District, Limpopo Province, South Africa. The site is 596 m above sea level and receives about 781 mm annual rainfall which is highly seasonal with 85% occurring between October and March during summer (Mzezewa *et al.*, 2011).

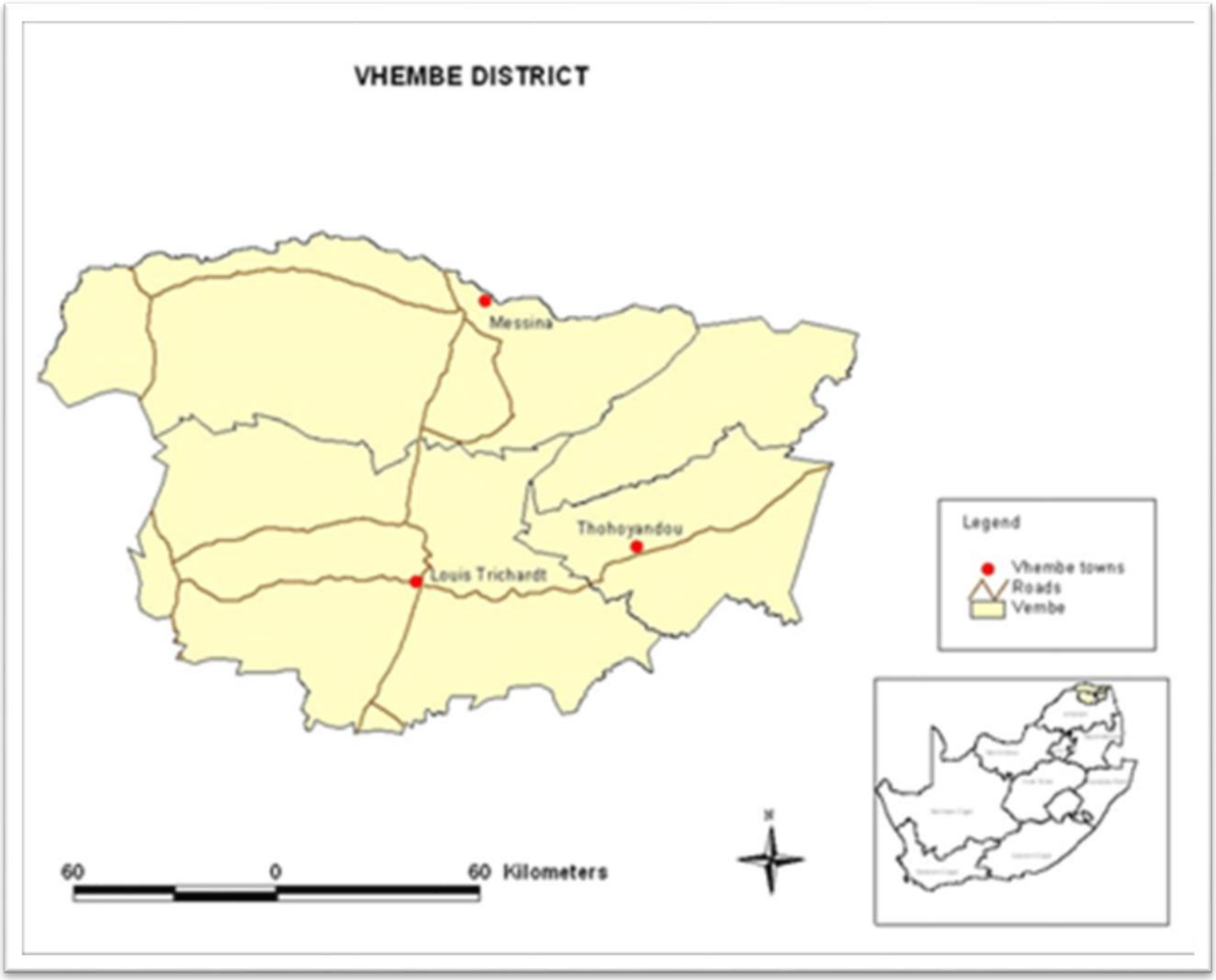

Figure 1: Location of study area *(adopted from Mzezewa and van Rensburg, 2011)*

The experimental area falls within the eastern part of the lowveld, forming the greater part of Limpopo River basin. The mean aridity index (AI) of the study area is 0.52 (Mzezewa *et al.*, 2011), classifying the area between semi-arid and sub-humid climatic zone according to the UNESCO classification systems. The soil of the study area is classified as Hutton soil form according to the South African Classification System (Soil Classification Working Group, 2018). The soil is deep (>1200 mm), characterized by high clay content and low bulk density (Mzezewa *et al.*, 2011), making it suitable for crop production.

3.2 Mulching material and application

The mulching material applied were dry leaves from avocado trees. Because avocado leaf mulch is lighter, decomposes quickly, and releases vital nutrients for usage by plants, it decreases the need for fertilizer application. The leaves were collected during the winter period when leaf fall was maximum. They were weighed to obtain the optimal weight for application. Three (3) treatments of avocado leaf mulch were applied to each plot two weeks after planting as follows: 0 (no mulch as control), 6 (dry avocado leaf mulch at 6 t/ha) and 12 (dry avocado leaf mulch at 12 t/ha). A layer of mulch was applied and leveled to cover each plot. Mulch treatments were randomly allotted as sub-plots for each tillage treatment.

3.3 The tillage methods

Two (2) tillage methods, conventional and minimum tillage were used in the study. Conventional tillage (CT) consisted of mouldboard plough, disk harrow and roller at the beginning of the experiment. Weeds were continuously removed using hand hoes including the removal of weed residues off the experimental plots. Minimum tillage (MT) consisted of small planting holes manually opened using a hand hoe. Seeds were sown in the planting lines and covered with soil. Chemical weed control was carried out in the wide rows while manual weeding was done within narrow rows. Tillage methods served as main plots during the experiment.

3.4 Experimental design and field layout

The experiment was laid out in a split plot design with three replications. The experimental set up was done during the 2018/19 and repeated in 2019/20 cropping seasons. This experiment was first started in the year 2018 when the study began. Treatments consisted of two (2) tillage methods (conventional tillage (CT) and minimum tillage (MT)) and three levels of avocado leaf mulch (0, 6 and 12 t/ha). The individual plot sizes measured 4 m × 5 m. The plots were spaced 1 m apart from each other to avoid infringement of organic mulch. During the whole trial period, no fertilizer was applied.

3.5 Plant population and spacing

NK Andiago sunflower seeds purchased from the nearest NTK were planted. Two (2) seeds were planted per hole at intra row spacing of 0.3 m and 1 m inter row spacing at an approximate depth of 2.5 cm in each plot. The seedlings were thinned to one stand per hole two (2) weeks after emergence. Therefore, plant population after thinning was approximately 66.666 plants per plot.

3.6 Soil sampling and analysis

Several soil samples were collected at 0 – 30 cm depth using a soil auger at the experimental area before the commencement of the experiment to characterize the soil. During the experiment, soil samples were collected on a fortnight basis at 5 (five) sampling points (1m from top left, top right, bottom left and bottom right corners and the center) within each plot and then mixed to make a composite sample. Collected soil samples were dried, sieved (through 2 mm sieve) and stored separately in laboratory plastic bags for subsequent physical and chemical analysis using the appropriate analytical methods. At the end of the cropping season, after termination of the experiment, representative soil samples were taken at the same depths for analysis. A total of 180 soil samples were collected and analyzed in 2 (two) cropping seasons.

3.7 Soil physical and chemical analysis for site characterization

3.7.1 Particle size distribution, soil cations, soil pH and EC

Particle size distribution was determined using Bouyoucos hydrometer method (Bouyoucos, 1936), where sodium hexametaphosphate (calgon) was used as a dispersant solution. Soil samples weighing 50 grams each were used for the analysis of particle size prior the commencement of the experiment. Soil cations were determined by the extraction and analysis of exchangeable cations (Ca^{++}, Mg^{++}, K^{+}, and Na^{+}) in soil. Exchangeable cations were extracted from the soil using an extracting solution (1 N NH_4OAc) at pH 7.0. The extracted solution was then analyzed by AA (atomic absorption) for the soil cations in mg/kg units (Thomas, 1982). Soil pH and EC were measured (in supernatant of a 1: 2.5 soil: water ratio) using a pH/EC/TDS Multi-meter probe (McLean, 1982).

3.8 Soil organic carbon

Soil organic carbon was analysed using Walkley-Black method (Walkley and Black, 1934).

3.9 Soil water content

On site measurements of soil water content was executed on a fortnight basis from planting to harvest using gravimetric method (Baker *et al.*, 1990) to a depth of 30 cm. Soil samples were taken using a bucket soil auger. A bucket soil auger was placed against the cleared soil surface and carefully pressed downwards into the soil until it was sufficiently filled with soil and then pulled from the surface. Soil samples were retained in pre-weighed and labelled paper bags. Collected soil samples were taken to the laboratory, be weighed for fresh wet weight and oven dried at 105 ^{o}C for 24 hours. Dry weight of soil samples was recorded after the soil has been dried. Soil water content (%) was calculated using the following formula:

$$\Theta g = \frac{m_{wet-} m_{dry}}{m_{dry}} \times 100 \qquad (1)$$

Where Θg = gravimetric water content (%)

m_{wet} = mass of wet soil (g)

m_{dry} = mass of dry soil (g)

3.10 Bulk density

Soil bulk density was determined using the core method (Blake and Hartge, 1986) at the beginning of the cropping season and at the end of the experiment. Soil samples were taken using a 98.17 cm^3 core ring (5 cm inner diameter and 5 cm height) with cylindrical core sampler. The core ring was fitted on a cylindrical core sampler, placed against the cleared soil surface. The ring was carefully pressed downwards into the soil until it was sufficiently filled with soil and then excavated from the surface with the aid of cylindrical core sampler. Both ends of core ring were trimmed with a trowel and put on the caps. Samples were collected at 0 – 30 cm depth. Collected soil samples were taken to the laboratory and oven dried at 105 °C for 24 hours. Bulk density was calculated using the following formula:

$$BD = m/V \quad (2)$$

Where *BD* = dry bulk density (g/cm^3)

m = mass of dry soil (g)

V = volume of soil (cm^3)

3.11 Infiltration rate

Soil infiltration rate was determined using a double ring infiltrometer method following the procedure described by Bouwer (1986) under dry soils. Double ring infiltrometer consisted of two (2) pairs of inner and outer rings, a driving plate, an impact absorbing hammer, measuring bridge and measuring rods with float (figure 2). The inner ring measured the following diameter × thickness × height (28 × 0.5 × 25 cm) while outer ring measured 53 × 0.5 × 25 cm. Small obstacles such as stones, twigs or bark chips were cleared before installation. Soil disturbance was kept as minimal as possible during installation of the double ring infiltrometer. A driving plate was on top of the rings and an impact absorbing hammer was used to simultaneously insert the infiltration rings about 5 cm vertically in to the soil. A measuring bridge and rod with a float were placed on the inner ring in order to prevent obstacles from hampering with the free movement of the float. Rings were filled with 25 liters of water and measurements of water level with time in the inner ring were recorded as indicated on the measuring rod in cm. Both shorter time interval (1 minute) and longer time interval (30 minutes) were used respectively from start to finish during the measurements. Measurements were stopped only when the infiltration rate was constant.

Cumulative time and time interval were determined by calculating the differences of time readings on the clock. Infiltration was determined by calculating water level differences. Infiltration rate (cm/hr.) was calculated by dividing infiltration by the time interval. Cumulative infiltration was determined by adding up the total amount of water infiltrating the soil from start to finish of the measurement.

Figure 2: Double ring infiltrometer kit *(adopted from www.soilmoisture.com)*

3.12 Aggregate stability

Soil aggregate stability was determined at 0 – 30 cm depth using wet sieving apparatus by Eijkelkamp Agrisearch Equipment (the Netherlands) as proposed by Moncada *et al.* (2013). The wet aggregate stability was determined on the principle that unstable aggregates will break down more easily than stable aggregates when immersed into water. To determine the stability, 8 sieves (with 60 Mesh screen) were filled with 4.0 g of 2 mm air dried soil aggregates. To prevent slaking of the aggregates when putting the filled sieves into the water filled (weighed and labelled) cans, the aggregates were pre-moistened with distilled water using a very fine plant sprayer. These sieves were placed in each labelled can filled with distilled water, which moved up and downward for a fixed time (3 minutes). Unstable aggregates fell apart and passed through the sieve and collected in the water-filled can underneath the sieve. After three (3) minutes, the cans were removed and replaced by another set of weighed and labelled cans filled with a dispersing solution (2 g sodium hydroxide (NaOH)/L). The sieves were immersed in labelled cans filled with 2 g NaOH/L, which moved up and downwards for about 5 to 8 minutes or more, until the materials smaller than the sieve screen openings have gone through. These cans contained the materials from the stable aggregates, except for sand particles too large to get through the sieve screen. Both sets of cans were placed in a convection oven at 110 °C until the water and NaOH solution had evaporated. After drying the cans with the aggregates, the weight of both stable and unstable aggregates was determined. The weight of stable aggregates was determined by weighing the can which was filled with dispersing solution, plus contents, and subtracting the weight of the can and consequently, subtracting the 0.2 g of the dispersing solute from the weight of the contents to obtain the soil weight. The weight of unstable aggregates was determined by weighing the can which was filled with distilled water, plus contents, and subtracting the weight of the can. Dividing the weight of stable aggregates over total aggregate weight gives an index for the aggregate stability.

3.13 Biomass sampling and yield determination

3.13.1 Plant height

Plant height measurements were taken during flower bud stage, flowering stage and at harvest maturing stage from marked five (5) middle row plants in each plot. Average plant height was determined for sampled plants. Measurements were taken using a thread and a tape measure. Plant height was measured from the base of the plant to the tip of the top most leaf.

3.13.2 Leaf area index

Leaf area (LA) of five (5) plants within the middle rows under respective treatments was measured by a leaf-area meter (LI-COR model 3100) at flower bud stage, flowering stage and harvest maturity stage. The LA was converted into the leaf area index (LAI). Leaf area meter was calibrated using square-shaped papers of known area. LAI was determined by dividing LA by the total area of sampled plants.

3.13.3 Dry matter

Plant samples were collected for above ground dry matter at flowering stage and harvest maturity stage. Five (5) plants in the second outer rows were sampled for each plot. Plant samples were partitioned in to leaves, heads and stems, and then dry matter was determined and expressed in kg/ha. The samples will be dried at 65 ^{o}C and dry mass will be measured using electronic weighing scale (Sartorius PMA 7500).

3.13.4 Yield components and grain yield

At physiological maturity, two (2) middle rows in each plot were harvested for yield component determination. Sunflower head diameter (cm) for each sampled plant was measured. Head dry matter (g/head) and total seed weight were measured. Seeds were oven dried at 65 ^{o}C for 24 hours to obtain optimal moisture content for grain yield. Grain yield was adjusted to 13% seed moisture content.

3.14 Statistical analysis

The data collected for growth and yield of sunflower, soil and other parameters was subjected to an analysis of variance (ANOVA) by using the factorial experiment with the split–split arrangement having tillage methods in the main plots and mulch levels in the sub plots. The IBM SPSS software, version 20 was used for the ANOVA. The treatment means were separated by least significant difference (LSD) when the analysis of variance F-test was significant at the $P \leq 0.05$ probability level. The following mathematical model to describe the relationship between the response and treatment for the One-way ANOVA (Neter *et al.*, 1996) was used:

$$Y_{ij} = \mu + I_i + \varepsilon_{ij} \quad (3)$$

Where Y_{ij} = the *j*-th observation (j = 1, 2,….n_i) on the *i*-th treatment (i = 1, 2,….,k levels).

μ = common effect for the whole experiment (overall mean).

Ii = the *i*-th treatment effect.

ε_{ij} = the random error present in the *j*-th observation on the *i*-th treatment.

4. Results

4.1 Selected soil physical and chemical properties for site characterization

The soil was dominated by clay fraction (56% clay), with low bulk density (BD) and low aggregate stability (AS), (Table 1a). The soil had a high infiltration rate (IR) with an average of 42.67 cm/hr (Table 1a) and was generally acidic with an average pH (H_2O) of 6.12 and pH (KCl) of 5.22 (Table 1b). The electrical conductivity (EC) of the soil was low (average 39.13 µS/cm), indicating a non-saline class on soil salinity classes (Van Rensburg *et al*., 2011). The soil had insufficient nutrients content required for general plant growth (Horneck, 2011). Calcium (Ca) was the dominant nutrient followed by magnesium (Mg), potassium (K) and sodium (Na), respectively, in that order.

Soil organic carbon (SOC) was high with an average of 1.91 %, representing the desired level for crop growth (Table 1b), (DEA, 2019).

Table 1: Selected soil physical and chemical properties at 0-30 cm depth for site characterization

(a) Soil physical properties

Particle size (%)			Textural class	BD (g/cm^3)	AS (g/g)	IR (cm/hr)
Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)				
32	12	56	Clay	1.21	0.83	42.67

BD = bulk density; AS = aggregate stability; IR = infiltration rate.

(b) Soil chemical properties

EC = electrical conductivity; SOC = soil organic carbon

pH (H_2O)	pH (KCl)	EC (µS/cm)	Exchangeable cations (mg/kg)				SOC (%)
			Na^+	K^+	Mg^{2+}	Ca^{2+}	
6.12	5.22	39.13	9	36	85	185	1.91

4.2 Climatic conditions

The temperature as well as rainfall were generally similar in both cropping seasons (Table 2). The maximum and minimum temperatures were slightly higher in the first cropping season (2018/19) as compared to the second cropping season (2019/20). During the 2018/19 cropping season, the highest maximum temperature was observed in December whereas in the 2019/20 cropping season, the maximum temperature was observed in November. The lowest minimum temperature (13.37°C) was experienced in November during the 2019/20 cropping season. The mean maximum temperature (T_{max}) was about 29°C while the mean minimum temperature (T_{min}) was about 17°C during the overall cropping period (2018/19 and 2019/20 seasons). The total rainfall received in the 2018/19 cropping season was slightly lower than the total rainfall received during 2019/20 cropping season (Table 2). The highest rainfall was received in January for both cropping seasons, where 54% (109.7 mm) of rainfall was received in 1 day in 2018/19 cropping season and 65% (138.1 mm) of rainfall was received in 2 days during the 2019/20 cropping season. Rainfall was fairly distributed in February for both cropping seasons with nearly the same number of rainy days. Rainfall was evenly distributed throughout the month of December, with the number of rainy days slightly higher in 2018/19 cropping season.

Table 2: Monthly temperature and rainfall during the experimental period in 2018/19 and 2019/20 cropping seasons.

Month	Max temp. (°C)	Min temp. (°C)	Total rainfall (mm)	No. of rainy days
		2018/19 cropping season		
December	30.35	17.84	121.4	14
January	28.55	17.61	202.1	9
February	28.93	17.93	33.0	6
March	28.84	17.13	40.1	3
Average	29.18	17.63	99.2	8
Total			396.6	32
		2019/20 cropping season		
November	28.73	13.37	124.4	9
December	28.13	17.06	61.2	9
January	27.65	17.74	211.6	8
February	27.38	16.83	82.0	7
Average	27.97	16.25	119.8	8.3
Total			479.2	33

4.3 Effects of tillage and mulching on selected soil properties

4.3.1 Soil organic carbon (SOC)

The effect of tillage practices on SOC was significant ($P<0.05$) at 56 DAP and 70 DAP during the 2018/19 cropping season and at 56 DAP and 84 DAP during the 2019/20 cropping season (Table 3). The SOC under MT treatment was 24% and 17% higher at 56 DAP and 70 DAP, respectively, than under CT treatment during the 2018/19 cropping season. A 14% decrease in SOC was recorded under the MT treatment at 56 DAP than under the CT treatment during the 2019/20 season. The MT treatment recorded 35% increase in SOC at 84 DAP during the 2019/20 cropping season as compared to the CT treatment. Similar SOC between the two tillage practices were obtained at 42, 84 and 98 DAP during the 2018/19 season and at 42, 70 and 98 DAP during the 2019/20 cropping season.

The application of avocado leaf mulch had no effect on soil organic carbon (SOC) during the two cropping seasons (Table 3). However, the SOC tended to decrease steadily in the control (zero mulch) treatment as compared to the 6 t/ha and 12 t/ha treatments as both seasons progresses. The 12 t/ha mulch treatment had slightly higher SOC content compared to the 6 t/ha treatment at 42, 56, 70, 84 and 98 DAP during the 2019/20 cropping season. In contrast, the SOC under the 6 t/ha treatment tended to be higher than under the control and 12 t/ha treatments at 56, 84 and 98 DAP during the 2018/19 cropping season. In general, the SOC content was the same in the three mulch treatments in the two cropping seasons.

A significant tillage × mulch rate interaction effect ($P<0.05$) was observed in SOC content at 42 DAP during the 2019/20 cropping season (Table 3; Figure 3). The SOC content was higher for the control treatment in CT compared to MT. Conversely, the SOC content was higher for the 6 t/ha and 12 t/ha mulch treatments in MT compared to CT.

Table 3: Mean soil organic carbon (SOC) (%) as affected by tillage and mulching during the 2018/19 and 2019/20 cropping seasons at UNIVEN.

Treatment	Days After Planting (DAP)				
	42	56	70	84	98
		2018/19 cropping season			
Tillage					
CT	1.91	1.82a	1.43a	1.64	1.28
MT	1.92	2.25b	1.68b	1.82	1.46
Mulch rate					
0	1.89	1.84	1.51	1.67	1.28
6	1.90	2.19	1.56	1.83	1.52
12	1.96	2.07	1.59	1.70	1.30
P value					
Tillage	ns	*	*	ns	ns
Mulch rate	ns	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns	ns
		2019/20 cropping season			
Tillage					
CT	1.81	1.78a	1.63	1.36a	1.49
MT	1.74	1.53b	1.75	1.83b	1.28

Mulch rate					
0	1.75	1.70	1.63	1.63	1.15
6	1.75	1.61	1.67	1.51	1.44
12	1.83	1.65	1.76	1.65	1.58
P value					
Tillage	ns	*	ns	*	ns
Mulch rate	ns	ns	ns	ns	ns
Tillage*Mulch rate	*	ns	ns	ns	ns

ns = not significant; * = significant at *P*<0.05. Different letters in the same column means significant difference.

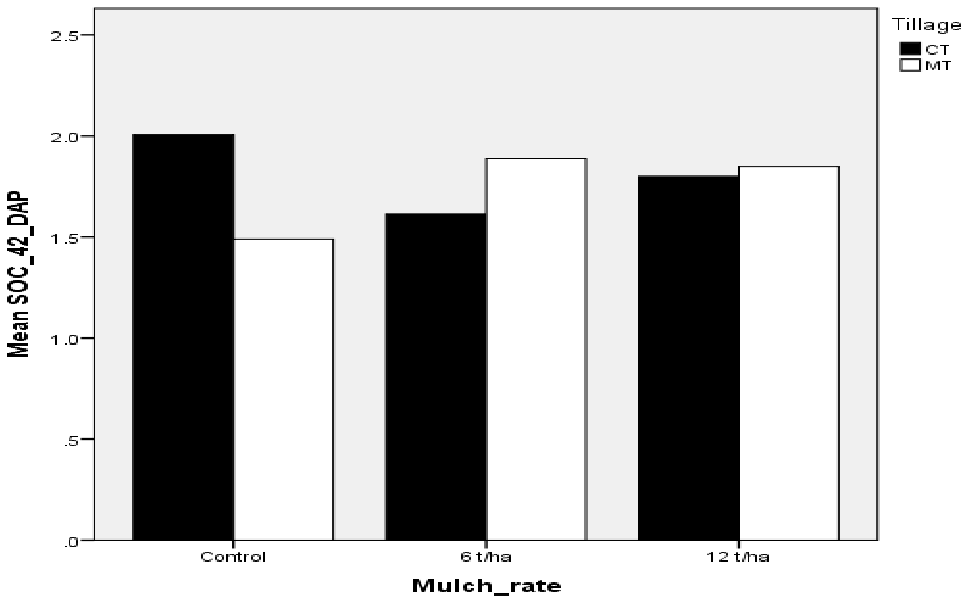

Figure 3: SOC (%) at 42 DAP as a function of mulch rate and tillage (2019/20 cropping season).

4.3.2 Soil water content (SWC)

The tillage practice had a significant effect (*P*<0.05) on SWC during the two cropping seasons (Table 4). The tillage practice influenced SWC only at 56 DAP and 70 DAP during the 2018/19 and 2019/20 cropping seasons, respectively. The SWC under the MT treatment was 9% lower and 24% lower, at 56 DAP (2018/19 season) and 70 DAP (2019/20 season) than under the CT treatment, respectively. In contrast, similar SWC were recorded between the two tillage practices at 42, 70, 84 and 98 DAP during the 2018/2019 cropping period and at 42, 56, 84 and 98 DAP during the 2019/2020 cropping period.

Avocado leaf mulch application had a significant (*P*<0.05) effect on soil water content (SWC) only during the 2019/20 cropping season at 42, 84 and 98 DAP (Table 4). At 12 t/ha and 6 t/ha mulch application, SWC was 11% and 12% higher, respectively, than under the control treatment at 42 DAP. At 84 DAP, the SWC under the 12 t/ha and 6 t/ha treatments were 24% and 17% higher than under the control treatment. The SWC under the 12 t/ha and 6 t/ha treatments was 11% and 7% higher, respectively, than under the control treatment at 98 DAP. Similar SWC were recorded between the three mulching treatments at 56 and 70 DAP during the 2019/20 cropping season. Moreover, similar SWC were obtained in the three mulch treatments at 42, 56, 70, 84 and 98 DAP during the 2018/19 cropping season (Table 4).

Table 4: Mean soil water content (SWC) (%) as affected by tillage and mulching during the 2018/19 and 2019/20 cropping seasons at UNIVEN.

Treatment	Days After Planting (DAP)				
	42	56	70	84	98
			2018/19 cropping season		
Tillage					
CT	22.26	28.02a	20.53	16.42	20.11
MT	23.20	25.41b	19.39	19.40	19.71
Mulch rate					
0	22.72	26.26	19.24	17.33	20.31
6	22.93	26.31	20.07	18.98	19.10
12	22.54	27.67	20.57	17.44	20.32
P value					
Tillage	ns	*	ns	ns	ns
Mulch rate	ns	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns	ns
			2019/20 cropping season		
Tillage					
CT	31.82	22.98	36.06a	24.07	28.69
MT	32.78	25.08	27.47b	23.52	28.18
Mulch rate					
0	30.02a	22.15	36.53	21.10a	26.82a
6	33.48b	25.83	30.83	24.55b	28.72b
12	33.40b	24.10	27.92	25.73b	29.77b
P value					
Tillage	ns	ns	*	ns	ns
Mulch rate	*	ns	ns	*	*
Tillage*Mulch rate	ns	ns	ns	ns	ns

ns = not significant; * = significant at $P<0.05$. Different letters in the same column means significant difference.

4.3.3 Bulk density (BD)

The tillage practice had no effect on BD during the two cropping seasons (Table 5). However, the MT treatment recorded a slightly higher BD (by about 11% higher) as compared to the CT treatment during the 2019/20 cropping season. The BD was slightly lower under the MT treatment (about 5% lower) than under the CT treatment during the 2018/19 cropping period. Generally, BD was nearly similar between the two tillage practices in the two cropping seasons.

The application of avocado leaf mulch had no effect on bulk density (BD) during the two cropping seasons (Table 5). However, the control treatment exhibited a slightly lower BD as compared to the 6 t/ha and 12 t/ha treatments during the 2018/19 season. The values of BD were similar in the three mulch treatments during the 2018/19 and 2019/20 cropping seasons.

4.3.4 Final Infiltration rate (IR) and Cumulative infiltration (CI)

Tillage had a significant effect ($P<0.001$ in 2018/19 and $P<0.05$ in 2019/20) on final IR during the two cropping seasons (Table 5). The MT treatment recorded a 32% higher final IR as compared to the CT treatment during the 2018/19 cropping season. However, during the 2019/20 cropping season the MT treatment had a 22% lower final IR as compared to the CT treatment. Tillage had a significant ($P<0.05$) effect on CI in the two cropping seasons (Table 5). The CI was lower under the MT treatment than under the CT treatment during the 2018/19 and 2019/20 cropping periods. Approximately 10% and 11% decrease in CI was observed under the MT treatment in the two cropping periods (2018/19 and 2019/20), respectively, as compared to the CT treatment.

Final Infiltration rate (IR) was not influenced by mulching during the two cropping seasons (Table 5). However, the application of avocado leaf mulch had a significant ($P<0.05$) effect on cumulative infiltration (CI), (Table 5). When mulching effect was compared between the two cropping seasons, it influenced CI only in the 2019/20 cropping season. The CI under the 12 t/ha mulch treatment was 9% higher than under the control treatment and 26% higher than under the 6 t/ha treatment during the 2019/20 cropping season. Similar CI were obtained in the three mulch treatments during the 2018/19 cropping season (Table 5).

A significant tillage × mulch rate interaction effect ($P<0.05$) was observed on final IR during the two cropping seasons (Table 5; Figure 4 and 5). The relationship between mulch rate and final IR depends on the method of tillage used. Minimum tillage with 6 t/ha and 12 t/ha mulch treatments were associated with the highest mean final IR compared to the control treatment during the 2018/19 cropping season. Conversely, CT with 6 t/ha mulch treatment was associated with the highest mean final IR compared to control and 12 t/ha mulch treatments during the 2018/19 cropping season (Figure 4). Minimum tillage with no mulch was associated with the highest mean final IR during the 2019/20 cropping season (Figure 5). In contrast, CT with 6 t/ha mulch treatment was associated with the highest final IR, respectively, followed by CT with 12 t/ha mulch treatment.

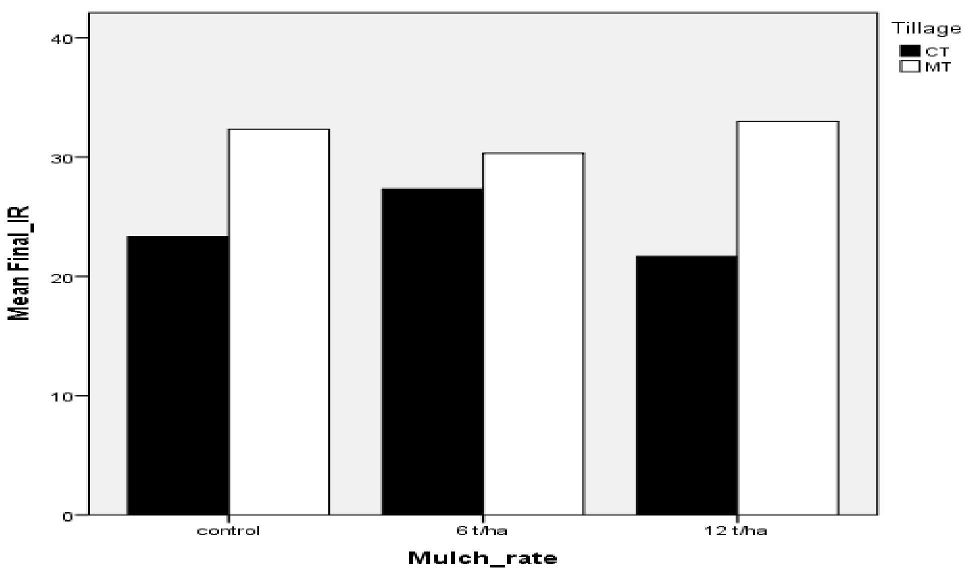

Figure 4: final IR (cm/hr.) as a function of mulch rate and tillage (2018/19 cropping season).

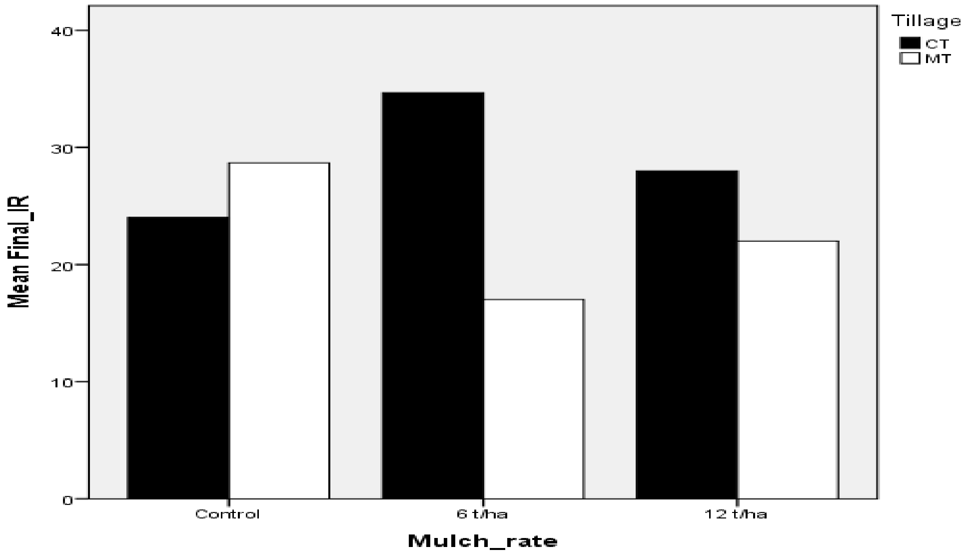

Figure 5: final IR (cm/hr.) as a function of mulch rate and tillage (2019/20 cropping season).

A significant tillage × mulch rate interaction effect (*P*<0.05) was observed in CI during the 2019/20 cropping season (Table 5; Figure 6). Conventional tillage with no mulch (control) and CT with 12 t/ha mulch treatment were associated with the highest mean CI. Conversely, MT with 6 t/ha was associated with the highest mean CI during the 2019/20 cropping season (Figure 6).

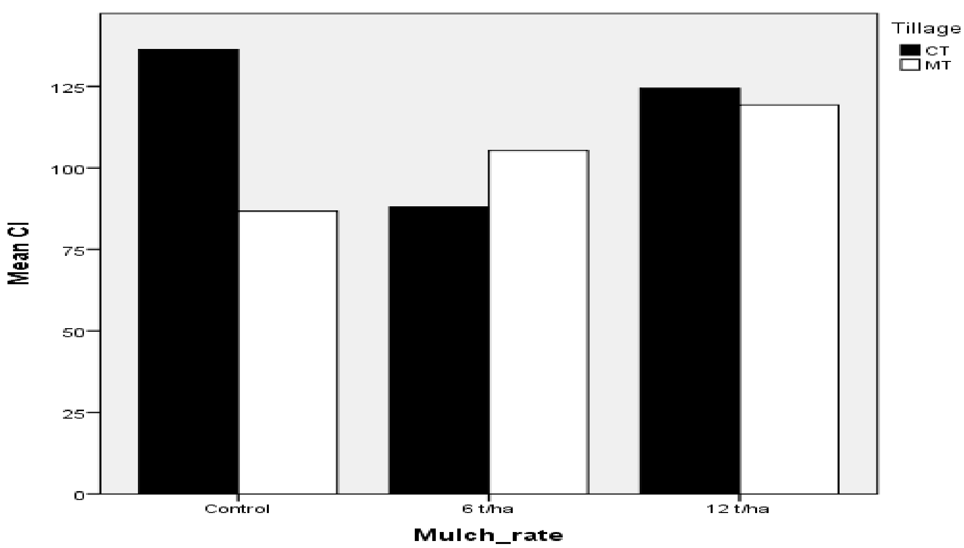

Figure 6: CI (cm) as a function of mulch rate and tillage (2019/20 cropping season).

4.3.5 Aggregate stability (AS)

Tillage had a significant (*P*<0.001) effect on AS only during the 2018/19 cropping season (Table 5). The AS in the MT treatment was 7% lower than in the CT treatment during the 2018/19 season. In contrast, similar AS between the two tillage treatments were obtained during the 2019/20 cropping season (Table 5).

The application of avocado leaf mulch had a significant (*P*<0.05) effect on aggregate stability (AS) only during the 2019/20 cropping season (Table 5). The control treatment had 4% lower AS compared to the 6 t/ha treatment and 9% higher than the 12 t/ha treatment during the 2019/20 season. In contrast, similar AS were recorded in the three mulch treatments during the 2018/19 cropping season (Table 5).

A significant tillage × mulch rate interaction effect (*P*<0.05) was observed on AS during the 2019/20 cropping season (Table 5; Figure 7). Minimum tillage with 6 t/ha mulch treatment was associated with the highest mean AS, followed by MT with no mulch, during the 2019/20 cropping season. In contrast, CT with 12 t/ha mulch treatment was associated with the highest mean AS during the 2019/20 cropping season (Figure 7).

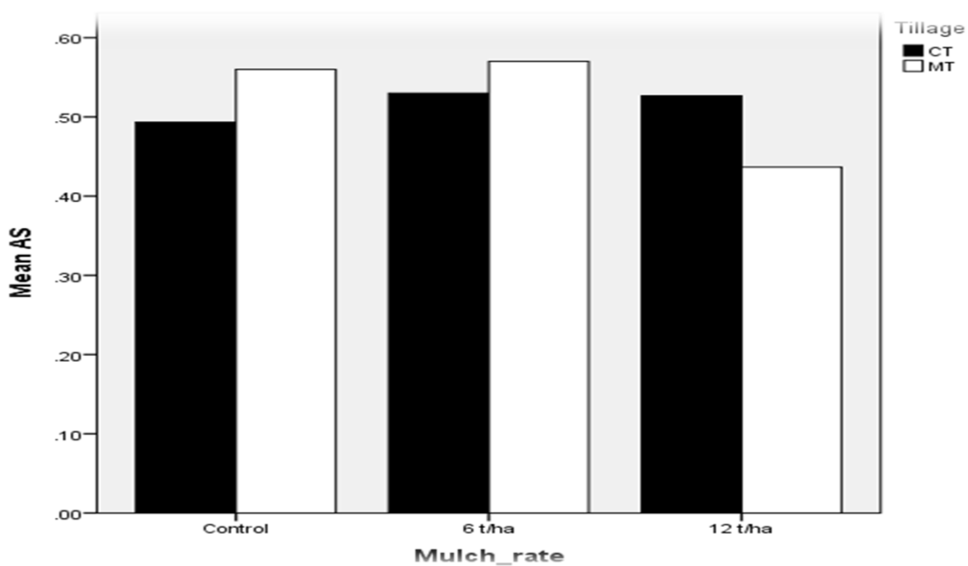

Figure 7: AS (g/g) as a function of mulch rate and tillage (2019/20 cropping season)

Table 5: Mean bulk density (BD), aggregate stability (AS), final infiltration rate (IR) and cumulative infiltration (CI) as affected by tillage and mulching during the 2018/19 and 2019/20 cropping seasons at UNIVEN.

Treatment	BD (g/cm^3)	Final IR (cm/hr.)	CI (cm)	AS (g/g)
		2018/19 cropping season		
Tillage				
CT	1.30	24.11a	170.87a	0.89a
MT	1.23	31.89b	154.36b	0.83b
Mulch rate				
0	1.23	27.83	167.55	0.85
6	1.27	28.83	155.88	0.86
12	1.29	27.33	164.40	0.87
P value				
Tillage	ns	***	*	***
Mulch rate	ns	ns	ns	ns
Tillage*Mulch rate	ns	*	ns	ns
		2019/20 cropping season		
Tillage				
CT	1.21	28.89a	116.33a	0.52
MT	1.34	22.56b	103.77b	0.52
Mulch rate				
0	1.28	26.33	111.55ab	0.53ab
6	1.23	25.83	96.70a	0.55a
12	1.32	25.00	121.90b	0.48b
P value				
Tillage	ns	*	*	ns
Mulch rate	ns	ns	*	*
Tillage*Mulch rate	ns	*	*	*

ns = not significant; * = significant at $P<0.05$; *** = significant at $P<0.001$. Different letters in the same column means significant difference.

4.4 Effects of tillage and mulching on sunflower growth and yield parameters

4.4.1 Plant height and leaf area index (LAI) at flower bud stage (FBS), flowering stage (FS) and harvest maturity stage (HMS)

Tillage had a significant ($P<0.05$) effect on plant height only during the 2018/19 cropping season (Table 6). Sunflower plant height in MT treatment was 30%, 10% and 8% higher than in CT treatment at FBS, FS and HMS, respectively, during the 2018/19 cropping season. Similar sunflower plant height was recorded at FBS, FS and HMS under the two tillage treatments during the 2019/20 cropping season.

Tillage had a significant (*P*<0.001) effect on sunflower LAI at FBS, FS and HMS only during the 2018/19 cropping season (Table 6). LAI was greater by 44%, 39% and 21% in the MT treatment at FBS, FS and HMS, respectively, than under the CT treatment during the 2018/19 cropping season. In contrast, similar sunflower LAI at FBS, FS and HMS were obtained between the two tillage practices during the 2019/20 cropping season.

The application of avocado leaf mulch had no effect on sunflower plant height and leaf area index (LAI) at FBS, FS and HMS during the two cropping seasons (Table 6). However, plant height tended to increase with an increase in mulching rate, thus 0 t/ha < 6 t/ha < 12 t/ha, respectively, at FBS, FS and HMS during the two cropping seasons. Generally, similar plant heights were recorded in the three mulch treatments in both cropping seasons (Table 6). The LAI showed a similar trend, whereby an increase in mulch rate resulted in an increase in LAI at FBS, FS and HMS during the 2018/19 and 2019/20 cropping seasons. Similar LAI values were obtained in the three mulch treatments in the two cropping seasons.

Table 6: Mean sunflower plant height and leaf area index (LAI) at flower bud stage (FBS), flowering stage (FS) and harvest maturity stage (HMS) as influenced by tillage and mulching during the 2018/19 and 2019/20 cropping seasons.

Treatment	Plant height (m)			LAI		
	FBS	FS	HMS	FBS	FS	HMS
			2018/19 cropping season			
Tillage						
CT	1.11a	1.64a	1.84a	1.11a	1.68a	2.23a
MT	1.44b	1.81b	1.99b	1.60b	2.34b	2.70b
Mulch rate						
0	1.30	1.72	1.89	1.34	2.05	2.47
6	1.31	1.75	1.94	1.37	1.98	2.46
12	1.22	1.71	1.91	1.35	2.00	2.46
P value						
Tillage	*	*	*	***	***	***
Mulch rate	ns	ns	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns	ns	ns
			2019/20 cropping season			
Tillage						
CT	1.47	1.56	1.66	0.61	0.81	1.01
MT	1.39	1.50	1.63	0.71	0.96	1.14
Mulch rate						
0	1.40	1.51	1.59	0.58	0.80	0.90
6	1.46	1.54	1.67	0.69	0.88	1.14
12	1.44	1.55	1.67	0.72	0.98	1.18
P value						
Tillage	ns	ns	ns	ns	ns	ns
Mulch rate	ns	ns	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns	ns	ns

ns = not significant; * = significant at $P<0.05$; *** = significant at $P<0.001$. Different letters in the same column means significant difference.

4.4.2 Dry matter at flowering stage (FS) and total biomass at harvest maturity stage (HMS)

Tillage had no effect on dry matter at FS and total biomass at HMS during the two cropping seasons (Table 7). However, the MT treatment recorded slightly lower sunflower dry matter and total biomass during the 2018/19 cropping season as compared to the CT treatment. In contrast, slightly higher sunflower dry matter and total biomass were recorded in the MT treatment than in the CT treatment during the 2019/20 cropping season. Generally, nearly similar sunflower dry matter and total biomass were obtained between the two tillage treatments during the two cropping seasons.

The application of avocado leaf mulch had no effect on dry matter at FS and total biomass at HMS during the two cropping seasons (Table 7). However, dry matter recorded during the 2019/20 cropping season was slightly higher than that of the 2018/19 cropping season in all the mulching treatments. The total biomass recorded during the 2018/19 cropping season was about three times higher than that recorded during the 2019/20 cropping season in all the mulch treatments.

Table 7: Mean sunflower dry matter at flowering stage (FS) and total biomass at harvest maturity stage (HMS) as influenced by tillage and mulching during the 2018/19 and 2019/20 cropping seasons.

Treatment	Dry matter (kg/plot)	Total biomass (kg/ha)	Dry matter (kg/plot)	Total biomass (kg/ha)
	FS	HMS	FS	HMS
	2018/19 cropping season		**2019/20 cropping season**	
Tillage				
CT	153.76	5.47	351.50	1.87
MT	116.91	5.26	477.47	2.34
Mulch rate				
0	115.87	5.25	358.45	1.77
6	142.94	4.77	447.33	2.36
12	147.19	6.06	437.67	2.18
P value				
Tillage	ns	ns	ns	ns
Mulch rate	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns

ns = not significant.

4.4.3 Head diameter, head dry weight, total seed weight and grain yield

Tillage had a significant (*P*<0.05) effect on sunflower head diameter only during the 2019/20 cropping season (Table 8). The MT treatment had 12% greater head diameter than the CT treatment during the 2019/20 cropping season. Similar sunflower head diameter between the two tillage treatments were obtained during the 2018/19 cropping season. Tillage had a significant (*P*<0.05) effect on sunflower head dry weight only during the 2019/20 cropping season (Table 8). The MT treatment recorded a 41% increase in head dry weight as compared to the CT treatment during the 2019/20 season. Similar results were obtained between the two tillage treatments in the 2018/19 cropping season (Table 8).

Tillage had a significant (*P*<0.05) effect on Sunflower total seed weight and grain yield only during the 2019/20 cropping season (Table 8). Minimum tillage total seed weight was 50% higher than under CT treatment. In contrast, similar total seed weight between the two tillage treatments were recorded during the 2018/19 cropping period. Minimum tillage sunflower grain yield was 45% higher than CT treatment during the 2019/20 season, whereas, similar grain yields were obtained between the two tillage treatments during the 2018/2019 cropping season (Table 8).

The application of avocado leaf mulch had no effect on head diameter in both seasons (Table 8). However, a slightly higher head diameter was recorded in all the mulch treatments during the 2018/19 cropping season as compared to the 2019/20 season. The control treatment recorded a slightly lower (6% lower in 2018/19 and 8% lower in 2019/20) head diameter as compared to the 6 t/ha and 12 t/ha treatments in the two cropping seasons. Generally, similar head diameter in the three mulch treatments were obtained during the two cropping seasons (Table 8).

The application of avocado leaf mulch had no effect on head dry weight in both seasons (Table 8). However, the head dry weight was much higher during the 2018/19 cropping season as compared to the 2019/20 cropping season in all the mulch treatments. The 6 t/ha treatment recorded higher (8% higher in 2018/19 and 13% higher in 2019/20) head dry weight during the two cropping seasons as compared to the control and 12 t/ha treatments. However, nearly similar head dry weights were recorded in the three mulch treatments during the two cropping seasons (Table 8).

The application of avocado leaf mulch had no effect on total seed weight and grain yield during the two cropping seasons (Table 8). The total seed weight was higher in all mulch treatments during the 2018/19 cropping season as compared to the 2019/20 cropping season. The grain yield was three times higher in all the mulch treatments during the 2018/19 cropping season as compared to the 2019/20 cropping season. However, similar total seed weight and grain yields in the three mulching treatments were recorded during the two cropping seasons (Table 8).

Table 8: Mean sunflower head diameter, head dry weight, total seed weight and grain yield as influenced by tillage and mulching during the 2018/19 and 2019/20 cropping seasons.

Treatment	Head diameter (cm)	Head dry weight (g/head)	Total seed weight (kg)	Grain yield (kg/ha)
		2018/19 cropping season		
Tillage				
CT	22.18	90.53	0.90	1804.44
MT	20.91	103.31	0.94	1880.00
Mulch rate				
0	20.70	93.74	0.89	1776.67
6	21.80	101.61	0.95	1903.33
12	22.14	95.40	0.92	1846.67
P value				
Tillage	ns	ns	ns	ns
Mulch rate	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns
		2019/20 cropping season		
Tillage				
CT	16.02a	27.70a	0.24a	488.89a
MT	18.01b	39.01b	0.36b	711.11b
Mulch rate				
0	16.15	31.01	0.28	550.00
6	17.57	36.07	0.30	600.00
12	17.33	32.80	0.33	650.00
P value				
Tillage	*	*	*	*
Mulch rate	ns	ns	ns	ns
Tillage*Mulch rate	ns	ns	ns	ns

ns = not significant; * = significant at $P<0.05$. Different letters in the same column means significant difference.

5. Discussion

5.1 Effects of tillage and mulching on selected soil properties

Significant variations in SOC were observed among the tillage treatments at 56 and 70 DAP and at 56 and 84 DAP during the 2018/19 and 2019/20 cropping seasons, respectively (Table 3). The consistently higher SOC at 56, 70 and 84 DAP in MT compared to CT could be attributed to minimum soil disturbance and less destruction of aggregates due to MT method (Kahlon *et al.,* 2013). In contrast, the CT promoted the formation of macroaggregates leading to lower SOC in bulk soil (Gao *et al.*, 2017). The results are consistent with the findings of Jacobs *et al.* (2009), who observed more SOC under MT in comparison to CT treatment at 0-5 cm and 10-20 cm depths on loamy Haplic Luvisols. The authors' further reported that nitrogen, microbial carbon, and microbial nitrogen concentrations were elevated under MT at both depths. Omara *et al.* (2019), reported significantly higher SOC under no-tillage (NT) than under CT on a silt loam soil texture.

A significant decrease in SOC at 56 DAP under MT compared to CT during the 2019/20 cropping season could be attributed to short-term splash erosion of rainfall and reduced incorporation of crop residues into the soil. Splash erosion occurs when raindrops hit the soil surface, breaking up soil aggregates and dislodging individual soil particles which in turn blocks the spaces between soil aggregates, forming a crust that reduces water infiltration and increases surface runoff (Kukal and Sarkar, 2010). This observation agrees with the findings of Liang *et al.* (2014), who observed a short-term decrease in silt organic carbon (OC) under no-tillage (NT) method in comparison to CT (or mouldboard plough) practice at 0-20 cm depth in a five-year field experiment on a clay loam soil. The authors' also reported that the increase in clay OC played an important role in the total increase in silt plus clay OC in NT compared to CT.

Although non-significant, the SOC was consistently higher under MT than under CT at 42, 84 and 98 DAP during the 2018/19 cropping season (Table 3). This observation is consistent with the findings of Dolan *et al.* (2006), who reported higher SOC in a 0-20 cm soil layer under NT than under CT and chisel plow treatments on a silt loam soil texture. The inconsistent and non-significant results in SOC that were observed between the two tillage treatments at 42, 70 and 98 DAP during the 2019/20 cropping season could be attributed to relatively shorter experimental cycle (2 years) under this practice. Similarly, lack of significant difference in SOC between the two tillage treatments at 42, 84 and 98 DAP and at 42, 70 and 98 DAP during the 2018/19 and 2019/20 cropping seasons, respectively, may be attributed to short-term practice of the MT method. Under long-term MT, the residue decomposition rate is slow and surface accumulation will result in high SOC (Dolan *et al.*, 2006). Also, long-term conservation tillage could enhance carbon protection, increase SOC levels and convert agricultural soils from carbon sources to carbon sinks (Paustian *et al.*, 1997b; Chevallier *et al.*, 2010; Lopez-Garrido *et al.*, 2011)

Avocado leaf mulch application resulted in no significant SOC content among all mulch treatments in the two cropping seasons (Table 3). This could be attributed to insufficient organic mulch (in this case, avocado leaf mulch) applied or slow decomposition of avocado leaf mulch to alter SOC significantly. The results are in line with the findings of Pal and Mahajan (2017), who reported no significant difference in SOC, regardless of the levels of mulch applied. Duiker and Lal (1999), also reported no significant differences in SOC under wheat straw mulch application and no-mulch application at 10-30 cm depth of silt loam soil. In our study, mulching increased SOC in both cropping seasons compared to no-mulch (control) treatment, irrespective of tillage methods. This might be attributed to the presence of more microbial activities in avocado leaf mulch treatments, which might have increased the SOC through decomposition of organic matter. Dong *et al.* (2018), reported a 16.9% increase in SOC under corn residue mulching compared to no-mulch treatment on silt loam soil.

Compared to MT, CT had significantly higher SWC at 56 and 70 DAP during the 2018/19 and 2019/20 cropping seasons (Table 4). This observation could be that the CT method loosened the clay soil and resulted in increased micropores, which promoted water infiltration. Salem *et al.* (2015), also reported greater SWC under CT than under MT at 0-25 cm soil layer of a loamy soil. Contrary to the findings of this study, Copec *et al.* (2015), found significantly higher SWC under no-tillage method compared to the CT method in a four-year study on a silty loam soil. The similarity in SWC response between the CT and MT at 42, 70, 84 and 98 DAP during 2018/19 and at 42, 56, 84 and 98 DAP during 2019/20 cropping seasons was most likely due to limited rainfall (Table 2) and short-term implementation of the MT method to alter SWC significantly as both seasons' progresses. Li *et al.* (2018), also found that there were no significant differences in SWC between CT and no-tillage treatments in a seven year experiment on a sandy loam soil texture.

The SWC was significantly influenced by avocado leaf mulch application of 6 t/ha and 12 t/ha at 42, 84 and 98 DAP during the 2019/20 cropping season (Table 4). The significant increase could be attributed to reduced evaporation of soil moisture and possibly slow air convection on the soil surface. The findings of this study are in agreement with the findings of Jordan *et al.* (2010), who reported that straw mulching significantly increased soil water storage than no-mulch treatment in a three year experiment under a semi-arid environment. The SWC was not influenced by avocado leaf mulch at 56 and 70 DAP during the 2019/20 and at 42, 56, 70, 84 and 98 DAP during the 2018/19 cropping season (Table 4). Nevertheless, the 6 t/ha and 12 t/ha avocado leaf mulch treatments had higher SWC compared to no-mulch treatment. The weak response in SWC among the mulch treatments observed in this study agree with the findings of Li *et al.* (2018), who reported no significant differences in SWC between straw mulch and no-mulch treatments on a sandy loam soil.

There was no significant difference in BD between the CT and MT in both cropping seasons (Table 5). Nevertheless, the BD was 4.9 % lower in CT compared to MT during the entire cropping seasons. This could be due to the fact that the soil in CT had been loosened by tillage, which may have temporarily relieved soil compaction. The results observed in this study are contrary to the findings by Salem *et al.* (2015), who found that the BD in MT was greater than that of CT in the upper soil layers of a loamy soil. Lack of significant difference in BD between the two tillage methods observed in this study is in agreement with the findings of Haruna *et al.* (2017), who found no significant difference in BD between tilled and untilled plots on a silt loam soil texture.

Avocado leaf mulch application resulted in no significant difference in BD among all mulch treatments in both cropping seasons (Table 5). Although non-significant, the BD was slightly lower under no-mulch treatment (control) compared to 6 t/ha and 12 t/ha mulch treatments in the 2018/19 season, whereas, the 6 t/ha mulch had slightly lower BD compared to no-mulch and 12 t/ha mulch treatments during the 2019/20 cropping season. Similar to the findings of this study, Duiker and Lal (1999), reported no significant difference in BD between wheat straw mulched and unmulched plots. In contrast, Kahlon *et al.* (2013), reported significantly higher BD under no-mulch treatment in contrast to 8 Mg/ha and 16 Mg/ha straw mulch treatments.

Significant variations in final IR and CI were observed between the two tillage methods in both cropping seasons (Table 5). Higher final IR in MT compared to CT during the 2018/19 season could be attributed to an increase in porosity due to relatively low BD brought about by the MT practice. However, the CT recorded a significantly higher final IR during the 2019/20 cropping season than the MT. This observation may be due to relieved soil compaction under the CT practice. Nonetheless, the MT had 2.7% increase in final IR compared to CT. The results of this study are in agreement with the findings of Williams and Wuest (2011). The CI that was consistently higher in CT compared to MT in both cropping seasons was probably due to reduced surface seal and less clogging of soil pores as a result of soil tillage. Jones *et al.* (1994), reported a decrease in CI under no-tillage compared to sweep tilled soils (in which a sweep plow is used to provide minimum disturbance of soil). Kahlon *et al.* (2013), found higher IR and CI in no-tillage system compared to plow tillage on a silt loam soil texture.

The application of avocado leaf mulch had no effect on final IR in both cropping seasons (Table 5). The results are in line with the findings of Kahlon *et al.* (2013), who also found that there were no significant differences in IR among all the wheat straw mulching treatments. Lack of significant difference observed in final IR in both seasons and in CI during the 2018/19 cropping season among the mulch treatments could be attributed to insufficient organic mulch applied or short-term implementation of the mulching treatments (2 years in this case) to alter final IR and CI significantly, similar to the findings of Barzegar *et al.* (2002). The CI was significantly influenced by avocado leaf mulch during the 2019/20 cropping season. The significantly higher CI under the 12 t/ha mulch treatment compared to the 6 t/ha mulch and no-mulch treatments could be attributed to the level of mulch applied, possibly increased microbial activity and the enhancement of soil macroporosity. Kahlon *et al.* (2013), reported higher CI under 16 Mg/ha wheat straw mulch rate, followed by 8 Mg/ha wheat straw mulch rate, then no-mulch treatment.

Tillage had a significant effect on AS during the 2018/19 cropping season (Table 5). The significantly higher AS in CT compared to MT could be attributed to the formation of microaggregates and the bonding of mineral particles. Clay soil conditions are characterized by lower net mineralization due to greater physical protection of soil organic matter from microbial attack (Verberne *et al.*, 1990). The results of this study are contrary to the findings of Kahlon *et al.* (2013), who reported greater water stable aggregates under no-tillage method compared to plow tillage on a silt loam soil texture. Although non-significant, a decrease in AS was observed during the 2019/20 season compared to the 2018/19 cropping season, irrespective of the tillage treatments. The weak response in AS between the two tillage methods during the 2019/20 cropping season is in agreement with the findings by Jacobs *et al.* (2010), who reported no significant difference in water stable aggregates between the MT and CT treatments on loamy Haplic Luvisols.

Avocado leaf mulch application had positive effect on AS during the 2019/20 cropping season (Table 5). The AS was significantly higher under the 6 t/ha mulch treatment as compared to the control (no-mulch) and the 12 t/ha mulch treatments. The results are in agreement with the findings of Jordan *et al.* (2010), who reported significantly greater AS in straw mulch plots than in no-mulch plots under cultivated soils from a three year experiment under semi-arid conditions. Similar results were reported by Simsek *et al.* (2017). The AS was slightly higher under mulched treatments in contrast to no-mulch treatment during the 2018/19 cropping season, although no significant variations were observed among all mulch treatments. Lack of significant difference in AS among wheat straw mulch treatments was also reported by Kahlon *et al.* (2013), on a silt loam soil texture.

5.2 Effects of tillage and mulching on sunflower growth and yield parameters

Tillage showed significant differences on sunflower plant height and LAI at all stages during the 2018/19 cropping season (Table 6). Minimum tillage recorded the highest plant height at FBS, FS and HMS than the CT treatment. This could be attributed to better utilization of water and nutrients in the field by the sunflower plant roots. Monero *et al.* (1997), also found that sunflower plant height was significantly higher under conservation tillage (no-tillage) than traditional tillage (conventional tillage) in a three year experiment on a sandy clay loam soil. Sunflower plant height showed no significant difference between the tillage methods during the 2019/20 cropping season, which is in agreement with the findings of Sessiz *et al.* (2008). Sessiz *et al*. (2008), found that sunflower plant height was not statistically significant among CT, no-tillage and reduced tillage methods in a two year experiment on a clay loam soil texture.

It was observed that LAI was significantly higher under MT than under CT during the 2018/19 cropping season (Table 6). This observation is in agreement with the findings of Monero *et al*. (1997), who reported the highest sunflower LAI in conservation tillage (no-tillage) than in traditional tillage (conventional tillage) on a sandy clay loam soil. Contrary to the findings of this study, Kumar and Angadi (2016), reported significantly greater chickpea leaf area (LA) in CT as compared to MT and no-tillage methods in a two year trial on black clay soil. Sunflower LAI showed no significant difference at all stages between the tillage methods during the 2019/20 cropping season. Lack of significant difference in sunflower LAI between the tillage treatments during the 2019/20 cropping season was probably due to a decrease in soil nutrients and nutrient mining by sunflower since the crop was planted consecutively in two seasons.

The application of avocado leaf mulch resulted in no significant difference in plant height in the two cropping seasons (Table 6). However, plant height tended to increase with mulch rate application at all stages, thus 0 t/ha< 6 t/ha< 12 t/ha, respectively, during the 2018/19 and 2019/20 cropping seasons. The results are in line with the findings of Zamir *et al.* (2013), who observed greater autumn maize plant height under wheat straw mulch than under no-mulch plots. The application of avocado leaf mulch resulted in no significant difference in LAI during the two cropping seasons (Table 6). The LAI, also tended to increase with mulch rate application at all stages during the 2018/19 and 2019/20 cropping seasons, respectively. Kumar and Angadi (2016), reported greater chickpea leaf area (LA) in dry maize stalk mulch treatments as compared to no-mulch treatment in a two year trial on black clay soil. The weak response in sunflower plant height and LAI among all mulch treatments was probably due to the low level of organic mulch applied or short-term implementation of the mulching treatments.

There was no significant difference in sunflower dry matter at FS between the two tillage methods in both cropping seasons (Table 7). Nonetheless, the MT recorded higher dry matter yield in the 2019/20 season in contrast to CT treatment. The results of this study agrees with the findings of Ishaque *et al.* (2018), who reported the highest maize dry matter yield in zero tillage system compared to CT system in a 5 year experiment under subtropical arid climatic conditions. The dry matter yield recorded in the 2019/20 cropping season in this study were higher than the values obtained in the 2018/19 cropping season at FS (Table 7). This observation could be attributed to the amount of rainfall received, in which the 2019/20 cropping season crop received more rainfall at the FBS and at FS as compared to the 2018/19 cropping season (Table 2).

There was no significant difference in total biomass at HMS between the two tillage methods in both cropping seasons (Table 7). However, MT recorded higher total biomass in the 2018/19 and 2019/20 cropping seasons in comparison to CT treatment. Contrary to the findings of this study, significantly higher chickpea total biomass was recorded under the CT plot in contrast to MT and zero tillage plots in a study conducted by Kumar and Angadi (2016), on a clay soil texture. The total biomass recorded in the 2019/20 cropping season in this study were lower than the values obtained in the 2018/19 cropping season at FS (Table 7). This decrease in sunflower total biomass at HMS in the 2019/20 cropping season may be as a result of early harvesting in the 2019/20 cropping season (98 days after planting) to avoid further damage of the sunflower crop by black birds compared to 126 days after planting (DAP) for the 2018/19 cropping season. This is also evidenced by a decrease in plant height and LAI at all stages in the 2019/20 cropping season.

The results of this study showed that sunflower dry matter at FS was statistically similar among all mulch treatments in the two cropping seasons (Table 7). Although non-significant, the 6 t/ha and 12 t/ha avocado leaf mulch treatments had higher dry matter yield in contrast to no-mulch treatment in both cropping seasons. This observation could be attributed to the low levels of organic mulch applied. Kumar and Angadi (2016), reported significantly higher chickpea dry matter yield in dry maize stalk mulch treatments as compared to no-mulch treatment in a two-year trial on black clay soil. Sunflower dry matter at FS recorded during the 2019/20 cropping season was slightly higher than that of the 2018/19 cropping season among all avocado leaf mulch treatments. This may be due to more rainfall received at FBS and at FS during the 2019/20 cropping season as compared to the 2018/19 cropping season (Table 2).

The results of this study also showed that total biomass was statistically similar among all mulch treatments in the two cropping seasons (Table 7). Nonetheless, the 6 t/ha and 12 t/ha avocado leaf mulch treatments recorded slightly higher total biomass as compared to no-mulch treatment in the 2018/19 and 2019/20 cropping seasons. The highest maize plant biomass under 4 Mg/ha, 8 Mg/ha and 12 Mg/ha wheat straw mulch treatments in contrast to no-mulch treatment was reported by Khurshid *et al.* (2006). The total biomass recorded during the 2018/19 cropping season was about three times higher than that recorded during the 2019/20 cropping season in all the mulch treatments. This observation was probably due to better utilization of soil water, soil nutrients and nutrient mining by the sunflower crop during the 2018/19 cropping season. This could also be attributed to sampling at late harvest maturity stage (126 DAP) when the crops had fully matured.

Conventional tillage recorded slightly higher head diameter than the MT in the 2018/19 cropping season, however, differences between the tillage methods were not significant. Similar to the findings of this study, Sessiz *et al.* (2008) found no significant differences in sunflower head diameter between no-tillage, CT and reduced tillage, in a two year experiment on a clay loam soil. The tillage methods in the 2018/19 cropping season recorded the highest head diameter compared to the 2019/20 cropping season in all treatments. Significant variations in sunflower head diameter were observed between the two tillage methods in the 2019/20 cropping season (Table 8). Minimum tillage recorded significantly higher head diameter than the CT treatment in the 2019/20 cropping season. The results are contrary to the findings by Ajayi (1997), who reported significantly higher sunflower head diameter under CT in contrast to zero tillage method in a three year experiment on a sandy loam soil texture.

Sunflower head dry weight was higher in the 2018/19 cropping season as compared to the 2019/20 season, irrespective of the tillage systems. The MT recorded higher sunflower head dry weight than the CT during the 2018/19 cropping season (Table 8). However, no statistical differences were observed in head dry weight between the CT and MT in the 2018/19 cropping season. Significant variations in sunflower head dry weight were observed between the two tillage methods only in the 2019/20 cropping season (Table 8). Minimum tillage (MT) recorded significantly higher head dry weight than the CT treatment in the 2019/20 cropping season. The lower values of head diameter and head dry weight recorded in the 2019/20 cropping season as compared to the 2018/19 cropping season may be due to lower soil nutrients and nutrient mining by sunflower since the crop was planted consecutively in two seasons (2018/19 and 2019/20 cropping seasons).

The results of this study showed that total seed weight was not affected by tillage in the 2018/19 cropping season (Table 8). Nonetheless, the MT recorded slightly higher total seed weight than the CT treatment in the 2018/19 cropping season. Zamir *et al.* (2013), observed the highest maize grain weight under zero tillage in contrast to CT on a clay soil texture. The total seed weight recorded during the 2018/19 cropping season was about three times higher than the values recorded during the 2019/20 cropping season. Significantly higher sunflower total seed weight was observed under MT in contrast to CT in the 2019/20 cropping season (Table 8). The results are contrary to the findings of Kumar and Angadi (2016), who reported higher chickpea grain weight under CT in contrast to MT and zero tillage systems on a clay soil texture.

There was no significant difference in sunflower grain yield between the two tillage methods in the 2018/19 cropping season (Table 8). Nevertheless, MT had slightly higher grain yield than CT during the 2018/19 growing season. Similar to the findings of this study, Sessiz *et al.* (2008), observed no statistical differences in sunflower grain yield among CT, no-tillage and reduced tillage methods in a two year experiment on a clay loam soil texture. Significant variations in sunflower grain yield were observed between the two tillage methods in the 2019/20 cropping season (Table 8). The MT recorded significantly higher grain yield than the CT treatment in the 2019/20 cropping season. The results are contrary to the findings by Kumar and Angadi (2016), who reported higher chickpea grain yields under CT in contrast to MT and zero tillage methods on a clay soil texture. The results correlates with the findings by Zamir *et al.* (2013), who found significantly higher maize grain yield in a zero tillage system compared to CT system on a clay soil texture. The grain yields recorded during the 2018/19 cropping season were higher than the values obtained during the 2019/20 cropping season, irrespective of the tillage systems. Even though the dry spells and heat stress (Table 2) coincided with the flowering stage (FS) of sunflower, the grain yields remained higher. This could be attributed to drought tolerance associated with sunflower.

Avocado leaf mulch application had no effect on sunflower head diameter and head dry weight in both cropping seasons (Table 8). The head diameter and head dry weight were much higher in all mulch treatments during the 2018/19 season as compared to the 2019/20 cropping season. Nonetheless, the 6 t/ha and 12 t/ha mulch treatments had greater head diameter and head dry weight as compared to no-mulch treatments in both cropping seasons. The decrease in sunflower head diameter and head dry weight during the 2019/20 cropping season could be attributed to early sampling in the 2019/20 cropping season (98 days after planting) in order to avoid further damage of the sunflower crop by birds, lack of soil nutrients and nutrients mining by the sunflower crop. The results are in line with the findings of Agele *et al.* (2010), who reported no statistical differences in sunflower head diameter among teak leaf mulch, dry grass mulch and no-mulch treatments in a two-year experiment. The author further reported no significant differences in sunflower seed yield among mulch treatments in the two cropping seasons.

The application of avocado leaf mulch had no effect on sunflower total seed weight in both cropping seasons (Table 8). The total seed weight was slightly higher in all mulch treatments during the 2018/19 cropping season as compared to the 2019/20 cropping season. This observation was probably due to early harvesting at HMS (98 DAP) in the 2019/20 cropping season to avoid further damage of the sunflower crop by birds as compared to 126 DAP in the 2018/19 cropping season. Nevertheless, the 6 t/ha and 12 t/ha mulch treatments recorded higher total seed weight than no-mulch treatments in both cropping seasons. The results of this study support the findings of Khurshid *et al.* (2006), who reported the highest maize grain yields under 4 Mg/ha, 8 Mg/ha and 12 Mg/ha wheat straw mulch treatments in contrast to no-mulch treatment.

Avocado leaf mulch application resulted in no statistical differences in sunflower grain yield in both cropping seasons (Table 8). The grain yield recorded during the 2018/19 cropping season was three times higher in all the mulch treatments as compared to the 2019/20 cropping season. The decrease in grain yield during the 2019/20 cropping season could be attributed to a decrease in soil nutrients and nutrient mining by sunflower since the crop was planted consecutively in two seasons. This may also be attributed to early harvest sampling (98 DAP) which was undertaken to avoid further damage of the sunflower crop by birds during the 2019/20 cropping season. Nonetheless, the 6 t/ha and 12 t/ha mulch treatments produced higher sunflower grain yields as compared to no-mulch treatments in both cropping seasons. The results of this study support the findings of Kumar and Angadi (2016), who observed higher chickpea grain yields in dry maize stalk mulch compared to no-mulch treatments.

5.3 Tillage × Mulch rate interaction effects

It has been reported that conservation tillage (minimum tillage (MT), no-tillage (NT)) with residue retention increases SOC content in soil and delays organic matter decomposition than soil with conventional tillage (CT) (Fuentes *et al.*, 2009). In the present study, the MT with 6 t/ha and 12 t/ha avocado leaf mulch treatments were associated with the highest SOC at 42 DAP during the 2019/20 season in contrast to the CT treatments with avocado leaf mulch application (Figure 3). Contrary to the findings of this study, Pal and Mahajan (2017), reported an increase in SOC under CT with pine needle mulch than in zero tillage with pine needle mulch. The tillage × mulch rate interaction indicated that the differences in SOC at 42 DAP in the two tillage practices can be explained, in part, by the differences in how the two tillage practices react to different levels of avocado leaf mulch.

Significant interactions between tillage and mulch rate was observed for final IR and CI during the two cropping seasons, except for CI in the 2018/19 cropping season (Figure 4, 5 and 6). The results suggested that the relationship between mulch rate and final IR and CI depended on the tillage method used. Moreover, the MT with avocado leaf mulch at 6 t/ha and 12 t/ha mulch had higher final IR than CT with mulch application during the 2018/19 cropping season. The CT with

6 t/ha and 12 t/ha mulch treatments had higher final IR than the MT with mulch application during the 2019/20 cropping season. The CI was significantly higher under mulched MT than under mulched CT during the 2019/20 cropping season. Ogban *et al.* (2008), also reported significantly higher equilibrium IR and CI under chromolaena odorata mulched no-tillage than chromolaena odorata mulched plow tillage plots.

Significant interaction between tillage and mulch rate was observed for AS during the 2019/20 cropping season (Figure 7). The MT with 6 t/ha mulch and the CT with 12 t/ha mulch were associated with the highest mean AS during the 2019/20 cropping season. The results of this study suggest that differences in AS could be explained, in part, by the differences in mulch rate application in the two tillage methods. The results are in line with the findings of Song *et al.* (2016), who reported greater water stable aggregates in zero tillage with straw mulch incorporation than in CT with straw mulch incorporation in a three-year rice-wheat rotation experiment.

6. Conclusions and recommendations

The present study investigated the effects of two tillage methods (conventional tillage (CT) and minimum tillage (MT)) and mulching (avocado leaf much at 0 t/ha (control), 6 t/ha and 12 t/ha) on selected soil properties, growth and grain yield of sunflower under rainfed conditions in Limpopo province. The tillage methods in this study influenced SOC, SWC, final IR, CI, and AS but had no effect on BD. The MT resulted in significantly higher SOC, final IR and AS than the CT method. However, the CT performed better than the MT with respect to SWC and CI in both seasons. The results from this study also showed the pronounced effects of tillage on sunflower growth and grain yields. The MT recorded significantly higher plant height and LAI than the CT method during the 2018/19 cropping season. Tillage had no effect on sunflower plant height and LAI during the 2019/20 growing season and on dry matter yield and total biomass in both seasons. The tillage methods significantly influenced sunflower head diameter, head dry weight, total seed weight and grain yield in the 2019/20 cropping season but had no influence in the 2018/19 cropping season. The MT performed better than the CT in the 2019/20 cropping season.

The application of avocado leaf mulch in this study influenced SWC, CI and AS, but had no effect on SOC, BD and final IR. The 6 t/ha and 12 t/ha mulch treatments had significantly higher SWC, CI and AS than no-mulch treatment. Avocado leaf mulch application had no effect on sunflower growth and grain yields in both cropping seasons. The interaction between tillage and mulch rate on SOC at 42 DAP indicated that the MT with 6 t/ha and 12 t/ha mulch treatments performed better than the CT treatments during the 2019/20 cropping season. Moreover, the CT with no-mulch had higher SOC at 42 DAP than the MT with no-mulch during the 2019/20 cropping season. Tillage × mulch rate interaction on final IR indicated that the MT at all mulch rates recorded higher mean final IR than the CT at corresponding mulch rates during the 2018/19 cropping season. In the 2019/20 cropping season, the CT with 6 t/ha and 12 t/ha mulch treatments had higher mean final IR than the MT with 6 t/ha and 12 t/ha mulch treatments. Tillage × mulch rate interaction on CI indicated that the MT with 6 t/ha and 12 t/ha mulch were associated with the highest mean CI than the MT with no-mulch during the 2019/20 cropping season. Conversely, the CT with no-mulch and 12 t/ha mulch had higher mean CI than the CT with 6 t/ha mulch. The interaction between tillage and mulch rate on AS indicated that the MT with no-mulch and 6 t/ha mulch treatments had higher mean AS than the CT with no-mulch and 6 t/ha mulch treatments during the 2019/20 cropping season. Conversely, the CT with 12 t/ha mulch performed better than the MT with 12 t/ha mulch, with respect to AS.

The results of the present study revealed that minimum tillage could be recommended to improve soil properties (organic carbon, infiltration rate and aggregate stability) of a clayey soil and also improve sunflower grain yields and growth. In addition, avocado leaf mulch application could be recommended to improve soil properties (organic carbon, bulk density, soil water content, infiltration rate, cumulative infiltration and aggregate stability), growth and grain yields of sunflower. It may also be recommended that in order to get a significant influence of mulching on sunflower growth and grain yields, further similar long term studies on organic mulch should be conducted. The application of minimum tillage and conventional tillage with avocado leaf mulch (6 t/ha and 12 t/ha mulch) could be recommended to improve soil organic carbon, infiltration rate, cumulative infiltration and aggregate stability of clayey soil. It should however be noted that for these recommendations to be made across sites based on grain yields, climatic conditions and soil type have to be considered. The results obtained in this study are, therefore, only valid for the specified soil and climatic conditions.

7. References

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8. Appendices

8.1 Appendix A: Effects of tillage and mulching on soil organic carbon (SOC)

Tillage method	Mulch rate (t/ha)	Replication	% SOC (2018/19 cropping season)					% SOC (2019/20 cropping season)				
			42 DAP	**56 DAP**	**70 DAP**	**84 DAP**	**98 DAP**	**42 DAP**	**56 DAP**	**70 DAP**	**84 DAP**	**98 DAP**
CT	**0**	**1**	1.76	1.05	1.25	1.17	1.01	2.06	1.87	1.67	0.91	1.52
		2	2.00	1.72	1.38	1.79	1.48	1.97	1.86	1.48	1.91	0.54
		3	1.94	1.93	1.40	1.72	1.21	1.99	1.74	1.61	1.45	1.82
	6	**1**	1.76	1.91	1.27	1.48	1.17	1.45	1.84	1.06	0.79	1.63
		2	2.02	2.01	1.46	1.58	1.38	1.67	1.81	1.57	1.84	1.69
		3	1.79	2.26	1.56	2.05	1.29	1.72	1.19	1.88	0.83	1.93
	12	**1**	2.15	1.64	1.64	1.44	1.38	1.75	2.10	1.70	1.61	0.84
		2	2.00	1.48	1.48	1.79	1.13	1.78	1.85	1.87	1.56	1.74
		3	1.75	2.42	1.46	1.74	1.44	1.87	1.79	1.81	1.36	1.74
MT	**0**	**1**	2.01	2.44	1.89	1.66	1.58	1.27	1.32	1.33	2.03	0.67
		2	1.84	2.32	1.46	1.77	1.33	1.38	1.78	1.75	1.88	1.17
		3	1.78	1.60	1.68	1.89	1.07	1.82	1.63	1.93	1.60	1.18
	6	**1**	2.34	2.24	1.68	1.95	1.95	1.75	1.69	1.93	2.08	1.43
		2	2.00	2.24	1.52	1.91	1.38	1.93	1.87	1.91	1.81	0.71
		3	1.46	2.48	1.88	2.01	1.97	1.98	1.28	1.70	1.72	1.27
	12	**1**	1.79	2.30	1.74	1.33	1.25	1.76	1.50	1.94	1.73	1.75
		2	2.15	2.32	1.38	1.97	1.19	2.00	1.51	1.75	1.87	1.75
		3	1.92	2.28	1.85	1.91	1.38	1.79	1.15	1.50	1.75	1.63

8.2 Appendix B: Effects of tillage and mulching on soil water content (SWC)

Tillage method	Mulch rate (t/ha)	Replication	% SWC (2018/19 cropping season)					% SWC (2019/20 cropping season)				
			42 DAP	56 DAP	70 DAP	84 DAP	98 DAP	42 DAP	56 DAP	70 DAP	84 DAP	98 DAP
CT	**0**	**1**	20.94	28.86	22.41	17.68	20.13	33.1	23.8	43.7	23.0	27.6
		2	23.12	24.93	20.79	15.43	22.22	30.6	27.8	48.6	18.6	26.4
		3	24.83	30.26	16.13	14.31	18.94	27.4	19.8	40.0	19.5	25.2
	6	**1**	20.53	28.22	21.91	19.90	20.19	35.6	26.1	29.5	27.5	28.9
		2	23.21	26.14	24.71	17.80	20.13	32.9	23.8	52.1	21.1	29.7
		3	22.72	26.67	14.59	11.77	17.61	29.7	23.2	25.7	27.7	27.7
	12	**1**	20.45	27.59	20.00	20.01	19.72	33.3	20.0	32.9	28.1	31.1
		2	22.79	26.72	20.79	14.48	21.01	31.4	18.8	25.9	27.1	31.0
		3	21.71	33.37	23.43	16.44	21.01	32.4	23.5	26.1	24.0	30.6
MT	**0**	**1**	21.92	24.56	17.74	18.09	19.50	27.4	15.6	22.1	19.8	26.5
		2	22.04	24.02	17.24	18.45	20.27	32.2	27.0	21.6	21.3	27.4
		3	23.47	24.94	21.14	20.01	20.82	29.4	18.9	43.2	24.4	27.8
	6	**1**	23.27	27.43	16.94	16.89	16.48	35.6	26.5	24.7	23.3	29.4
		2	22.74	26.09	21.84	20.37	20.47	33.8	28.2	27.4	20.6	29.6
		3	25.12	23.28	20.45	27.14	19.72	33.3	27.2	25.6	27.1	27.0
	12	**1**	24.55	25.20	13.76	16.27	18.46	33.5	28.6	29.6	23.9	28.7
		2	23.04	26.12	22.75	21.00	21.29	36.1	25.0	27.1	25.5	29.8
		3	22.68	27.01	22.67	16.41	20.41	33.7	28.7	25.9	25.8	27.4

8.3 Appendix C: Effects of tillage and mulching on bulk density (BD) and aggregate stability (AS)

Tillage method	Mulch rate (t/ha)	Replication	BD (g/cm^3)	AS (g/g)	BD (g/cm^3)	AS (g/g)
			2018/19 cropping season		2019/20 cropping season	
CT	0	1	1.23	0.89	1.2	0.40
		2	1.22	0.85	1.3	0.52
		3	1.15	0.86	1.0	0.56
	6	1	1.36	0.89	1.2	0.51
		2	1.28	0.90	1.2	0.53
		3	1.34	0.88	1.3	0.55
	12	1	1.35	0.87	1.4	0.55
		2	1.24	0.93	1.1	0.53
		3	1.52	0.90	1.2	0.50
MT	0	1	1.31	0.84	1.3	0.56
		2	1.34	0.84	1.7	0.57
		3	1.15	0.81	1.2	0.55
	6	1	1.08	0.85	1.3	0.58
		2	1.25	0.82	1.2	0.55
		3	1.30	0.81	1.2	0.58
	12	1	1.15	0.84	1.2	0.44
		2	1.30	0.86	1.4	0.43
		3	1.19	0.84	1.6	0.44

8.4 Appendix D: Effects of tillage and mulching on final infiltration rate (IR) and cumulative infiltration (CI)

Tillage method	Mulch rate (t/ha)	Replication	Final IR (cm/hr.)	CI (cm)	Final IR (cm/hr.)	CI (cm)
			2018/19 cropping season		2019/20 cropping season	
CT	**0**	**1**	24	193.5	25	132.0
		2	22	174.43	23	152.7
		3	24	158.6	24	124.5
	6	**1**	30	147.5	35	89.9
		2	25	163.3	31	83.9
		3	27	164.9	38	90.5
	12	**1**	20	176.7	28	127.5
		2	23	178.0	20	126.6
		3	22	184.1	36	119.4
MT	**0**	**1**	34	160.7	29	82.9
		2	32	152.0	28	84.8
		3	31	169.3	29	92.4
	6	**1**	34	150.2	17	100.3
		2	28	152.1	22	96.8
		3	29	157.3	12	118.8
	12	**1**	35	156.4	18	143.0
		2	30	149.4	26	112.6
		3	34	141.8	22	102.3

8.5 Appendix E: Effects of tillage and mulching on sunflower plant height and leaf area index (LAI)

Tillage method	Mulch rate (t/ha)	Replication	2018/19 cropping season						2019/20 cropping season					
			Plant height (m)			Leaf area index (LAI)			Plant height (m)			Leaf area index (LAI)		
			FBS	FS	HMS	FBS	FS	HMS	FBS	FS	HMS	FBS	FS	HMS
CT	0	1	0.97	1.67	1.84	1.16	1.78	2.25	1.55	1.61	1.74	0.59	0.82	0.91
		2	0.99	1.48	1.74	1.23	1.98	2.38	1.38	1.49	1.52	0.51	0.72	0.80
		3	1.39	1.80	1.93	1.06	1.56	2.08	1.40	1.54	1.60	0.66	0.78	0.92
	6	1	1.29	1.81	1.92	1.08	1.71	2.26	1.50	1.58	1.61	0.42	0.61	0.76
		2	0.75	1.33	1.63	0.91	1.43	2.03	1.46	1.65	1.71	0.60	0.86	1.14
		3	1.35	1.81	1.98	1.26	1.69	2.34	1.50	1.53	1.67	0.74	0.90	1.18
	12	1	0.96	1.54	1.86	0.97	1.64	2.27	1.52	1.59	1.76	0.57	0.77	0.96
		2	0.96	1.58	1.75	1.07	1.62	2.16	1.44	1.49	1.53	0.61	0.80	1.08
		3	1.31	1.75	1.91	1.24	1.67	2.30	1.46	1.60	1.79	0.78	1.02	1.32
MT	0	1	1.35	1.70	1.90	1.44	2.28	2.70	1.44	1.61	1.70	0.69	0.91	1.14
		2	1.45	1.80	1.95	1.61	2.35	2.72	1.28	1.37	1.44	0.42	0.74	0.78
		3	1.64	1.88	2.00	1.54	2.32	2.67	1.32	1.44	1.51	0.59	0.80	0.86
	6	1	1.73	2.04	2.15	1.83	2.27	2.65	1.46	1.53	1.88	1.19	1.26	1.71
		2	1.32	1.78	1.97	1.54	2.35	2.69	1.49	1.56	1.67	0.78	1.06	1.30
		3	1.41	1.74	1.96	1.58	2.43	2.79	1.33	1.41	1.50	0.40	0.56	0.76
	12	1	1.46	1.83	2.05	1.55	2.40	2.76	1.52	1.60	1.76	0.80	1.36	1.45
		2	1.51	1.86	2.04	1.56	2.33	2.65	1.48	1.65	1.71	0.91	1.01	1.29
		3	1.11	1.67	1.86	1.71	2.35	2.64	1.22	1.36	1.49	0.62	0.91	0.97

8.6 Appendix F:Effects of tillage and mulching on sunflower dry matter at flowering stage (FS) and total biomass at harvest maturity stage (HMS)

Tillage method	Mulch rate (t/ha)	Replication	2018/19 cropping season		2019/20 cropping season	
			Dry matter (g/plot)	Total biomass (kg/ha)	Dry matter (g/plot)	Total biomass (kg/ha)
			FS	HMS	FS	HMS
CT	0	1	80.97	5.90	371.5	2.03
		2	133.20	6.10	295.9	1.38
		3	190.13	5.55	384.6	1.43
	6	1	214.10	3.95	228.4	1.53
		2	136.53	5.35	374.2	2.18
		3	185.93	6.60	324.5	2.43
	12	1	86.11	4.40	416.1	1.67
		2	192.98	6.00	321.5	1.87
		3	163.87	5.35	446.8	2.28
MT	0	1	117.2	3.75	533.9	2.34
		2	86.0	3.31	232.4	1.53
		3	87.7	6.90	332.4	1.93
	6	1	141.4	4.22	806.1	4.16
		2	98.4	5.14	568.2	2.43
		3	81.3	3.38	382.6	1.40
	12	1	233.4	5.28	647.3	3.05
		2	117.8	5.05	364.5	2.24
		3	89.0	10.30	429.8	1.99

8.7 Appendix G: Effects of tillage and mulching on sunflower head diameter, head dry weight, total seed weight and grain yield

Tillage method	Mulch rate (t/ha)	Replication	2018/19 cropping season				2019/20 cropping season			
			Head diameter (cm)	Head dry weight (g/head)	Seed weight (kg)	Grain yield (kg/ha)	Head diameter (cm)	Head dry weight (g/head)	Seed weight (kg)	Grain yield (kg/ha)
CT	0	1	19.86	104.22	0.89	1780	16.1	30.74	0.25	500
		2	22.39	90.07	0.73	1460	15.8	25.30	0.20	400
		3	21.86	95.75	1.07	2140	15.3	28.91	0.25	500
	6	1	22.72	57.01	0.56	1120	16.3	26.01	0.20	400
		2	22.09	82.18	1.19	2380	16.2	31.38	0.25	500
		3	24.22	131.58	1.12	2240	16.5	33.37	0.20	400
	12	1	19.83	71.79	0.70	1400	15.6	22.65	0.25	500
		2	22.44	91.38	1.02	2040	16.1	18.69	0.30	600
		3	24.24	90.71	0.84	1680	16.3	32.29	0.30	600
MT	0	1	20.23	91.42	0.76	1520	16.4	38.30	0.40	800
		2	19.40	75.49	0.76	1520	16.3	29.33	0.30	600
		3	20.43	105.46	1.12	2240	17.0	33.48	0.25	500
	6	1	20.97	118.01	1.02	2040	21.0	55.63	0.50	1000
		2	20.59	101.09	0.91	1820	19.3	44.33	0.40	800
		3	20.21	119.79	0.91	1820	16.1	26.90	0.25	500
	12	1	20.88	119.07	0.77	1540	20.2	51.11	0.45	900
		2	20.29	95.84	0.84	1680	17.8	35.46	0.30	600
		3	25.17	103.59	1.37	2740	18.0	36.58	0.35	700