MODELLING THE EFFECTS OF MULCH APPLICATION RATES ON COWPEA GROWTH, YIELD AND SOIL WATER CONTENT USING APSIM

By

Selamolela K.E.

11628682

Dissertation for Master of Science (MSc) degree in Agriculture (Soil Science)

Department of Soil Science

School of Agriculture

University of Venda

Thohoyandou, Limpopo

South Africa.

DECLARATION

I, Kamogelo Evidence Selamolela, declare that this thesis is my original work and has not been submitted for any other degree at any other university or institution. The dissertation does not contain other persons' writing unless specifically acknowledged and referenced accordingly.

Signed (Student): Date: 28/08/2020

As the supervisor/co-supervisor of the above candidate, we agree to the submission of this dissertation.

Supervisor: Prof. J.J.O Odhiambo 30 August 2020

Signature Date

Co-Supervisor: Dr M. Hoffmann 31-Aug-2020

Signature Date

ACKNOWLEDGEMENTS

I extend my deepest gratitude to the following people and institutions.

Prof. J.J.O Odhiambo for your patience and advice throughout my studies. I have learnt a lot from you about soil science.

Dr M Hoffmann for your guidance throughout my study.

Prof. P.O. Adesoye for the interest you showed in my studies, as well as, giving me so much time and resources and for the excellent invaluable advice during data analysis.

Nompumelelo Mobe for constantly being a source of encouragement and the support you gave in many ways and for all that I have learned from you about the model APSIM and statistical analysis.

My parents, Mmadi and Kelepe Matabane, thank you for the constant support and always encouraging me to study further even when you didn’t know how you would pay for my fees. Thank you for all your sacrifices

My brothers Lebogang and Tshegofatso Matabane and my surrogate sister Livhalani Netshisaulu, thank you for always showing me the brighter side of life throughout my long student life.

My late mother in-law Rose Tshiwela Mapula Selamolela thank you for giving me the best gift and all your motherly advice. You live on in our hearts.

Department of Agriculture and Forestry (DAFF) for their financial support throughout my studies as well as the National Student Fund (NRF).

DEDICATION

To my children, Mapula and Donald Selamolela, you are a constant source of encouragement and motivation. I hope you will exceed above and beyond your own expectations. Never let the world define who you are. I dare you to live your dreams. To my husband, Mpho Donald Selamolela, your patience support and prayers will never be forgotten. Thank you for having so much confidence in me.

ABSTRACT

Early maturing crops that are drought-adapted together with mulch application have the potential to stabilize and increase dryland crop yields in semi-arid regions of the world. Agricultural systems models worldwide are increasingly being used to explore options and solutions for food security. Agricultural Production Systems Simulator (APSIM) is one such model that continues to be applied and adapted to meet this challenge. The APSIM model was used to assess the impact of different mulch application rates on cowpea grown under dry conditions in Vhembe district of South Africa.The objective of the study was to evaluate soil water content, crop water use efficiency (WUE), grain yield and the dry matter response of cowpea (*Vigna unguiculata* (L)) and validate the results using the model APSIM. Data taken from the study under optimum growth conditions was used to parametize the ASPSIM model. Soil water and fertility parameters measured were used for simulations while the same starting conditions were assumed for unmeasured parameters for all trials. Field experiments were conducted over two seasons (2016/17 and 2017/18). Treatments consisted of four levels of mulch application (0, 2, 4 and 8 t/ha) arranged in a randomized complete block design (RCBD) and replicated four times. The following parameters were measured: dry matter, grain yield, water use efficiency and soil water content. The data collected was subjected to analysis of variance using the randomised complete block design (RCBD) model and analyzed using the Statisticsl Analysis Systems (SAS) version: 9.4 at $P \leq 0.05$ probability level. The perfomance of APSIM model was evaluated using root mean square error (RMSE), coefficient of efficiency (E_i), root mean square deviation (RMSD) and median unbiased absolute percentage error (MdUAPE). There were no significant differences ($p>0.05$) in dry matter accumulation at flowering stage and harvesting stage amongst seasons. The highest cowpea yields were achieved at 8 t/ha mulch rate in both the 2016/17 and 2017/18 cropping seasons (11144.0 kg/ha and 9705.6 kg/ha) respectively. Mulch application rates had significant ($p<0.05$) differences on grain yield in 2016/17 (2049 kg/ha <2232.5 kg/ha <3341 kg/ha <3631 kg/ha) and 2017/18 (1291 kg/ha <1774 kg/ha< 2965 kg/ha <3594 kg/ha). The season effect of grain yield was not significant. There were no significant differences in soil water content among treatments as well as between seasons. There were no significant differences among the treatments in terms of ET; however, there was a significant ($p<0.05$) difference between the seasons. In both seasons, the 4 t/ha mulch application rate recorded the highest ET (139.17 mm and 125.83 mm in 2016/17 and 2017/18 seasons, respectively). The effect of treatments in terms of water use efficiency was found to be significant ($p<0.05$), with the highest WUE found to be at the 4 t/ha and 8 t/ha mulch application rate, with 4 t/ha being the highest (24 kg/ha/mm and 24 kg/ha/mm, in 2016/17 and 2017/18 seasons, respectively). R^2 for both seasons was 0.5 for yield and dry matter at harvest. RMSE for yield was found to be 0.3 in both the 2016/17 and 2017/18 cropping seasons. E_i was recorded at 0.9. RMSE for total dry matter at harvesting stage was calculated to be 0.3 and the 0.4, during the 2016/17 and 2017/18 seasons, respectively. At flowering RMSE was found to be 0.2 for both seasons and E_i to be 0.9.

Key words: APSIM, cowpea, mulch, yield, water use efficiency,

LIST OF ABBREVIATIONS

WUE - Water Use Efficiency

RMSD - Root Mean Square Deviation

RMSE - Root Mean Square Error

APSIM - Agricultural Production Systems Simulator

SWC – Soil Water Content

ET - Evapotranspiration

Mg^{2+} - Magnesium

K^{+} - Potassium Ion

Ca^{2+} - Calcium Ion

P - Phosphorus

N - Nitrogen

DUL - Drained Upper Limit

CLL – Crop Lower Limit

MdUAPE – Median Unbiased Absolute Percentage Error

BD – Bulk Density

t/ha – Ton per hectare

kg/ha – Kilogram per hectare

T_{min} – Minimum temperatures (°C)

T_{max} – Maximum temperatures (°C)

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER ONE

1. Introduction

1.1 Background information

Ninety-five percent of the current population growth occurs in developing countries and a large proportion relies on rain-fed food production (Rockstrom *et al*., 2003). Fifty-eight percent of the world's food production comes from rain-fed agriculture (Rosegrant *et al.,* 2002). Irrigation development assistance from major international donors has been on the decline over the years (IFPRI, 2011). Therefore, food production and rural livelihoods will continue to rely on rain-fed agriculture in the foreseeable future. Cowpea (*Vigna unguiculata* (L) *Walp*) is a major food crop in Africa and it plays a vital role in the diet of millions of people. Cowpea legume is a multi-purpose legume crop from which farmers derive animal feeds and cash income (Singh *et al*., 2003; Hall, 2012). Cowpea is a very important grain legume crop which provides food security and employment to many farmers in South Africa. Small-scale farmers, who are the largest producers of cowpea in South Africa, are adversely affected by dryland farming conditions (DAFF, 2011).

Cowpea is a protein rich grain that supplements staple cereal and starchy tuber crops. Cowpea is an annual legume commonly referred to as southern pea and black eye pea, amongst many other names. This legume is a warm season crop adapted to many areas of the humid tropics and temperate zones. Cowpea is extremely tolerant to heat and dry conditions, but it is intolerant of frost (DAFF, 2011). Once harvested, cowpea is suitable for hay, silage and pasture. It has a dense canopy and total dry matter production can reach 6900 kg/ha (Tarawali *et al*., 1997), which makes it suitable as a cover crop for soil and water conservation purposes. Planting can be done under both irrigated and non-irrigated regimes. An added advantage of cowpea is that it can extract stored soil water from deeper depths and tolerates extended periods of water deficits (Hall, 2012). Seed maturity can be reached within 60 days and the crop can be planted during periods otherwise used for summer fallow (Moroke *et al*., 2011).

Cowpea is more drought tolerant than the common bean. This is one of the main reasons it is such an important crop in many underdeveloped parts of the world (Ribeiro *et al*., 2004). The edible beans are the primary reason for growing cowpea, although the green, leaves and pea pods are consumable, cowpea can thus be used as a food source before the dried peas harvested (Jayathilake *et al*., 2018)). Despite the importance of cowpea, the yields have remained low under rain-fed agriculture in arid and semi-arid regions. This is due to low and erratic rainfall, high evapotranspiration rates, low soil fertility and land degradation (Jaetzold *et al*., 2006). Besides its agronomic and environmental adaptation and benefits, cowpea offers producers market opportunities and potential grazing feeds.

Water and its efficient use are a growing concern for agricultural production worldwide, particularly in dryland regions (Rockstrom and Barron 2007; Vorosmarty *et al*., 2010). According to the United Nations Environment Programme (2007), approximately eighteen percent of the earth's land surface is semi-arid land that is indispensable for global food production. Limited groundwater, low precipitation and high-water losses combine to make water scarcity the main limiting factor for primary production in rain-fed semi-arid areas (Deng *et al*., 2006; Hatibu *et al*., 2006). Positive effects of mulch on increasing soil water and temperature, growth, yield and water use efficiency have been well reported (Dong *et al*., 2018; Yang *et al*., 2018). Fan *et al*. (2017) indicated that mulch accelerated plant growth and advanced maize maturity, finally increased yield and WUE in maize field. Several studies have shown that an irregular temporal distribution and inefficient management of rainwater, rather than total rainfall, are the primary constraints on crop production (Barron *et al*., 2003; Rockstrom *et al*., 2010).

It has also been reported that adopting optimized water and soil management strategies to bridge water limitations during dry spells can markedly promote crop growth and increase yields (Barron *et al*., 2003; Lui *et al*., 2010; Rockstrom *et al*., 2010; Nyakudya and Stroosnijder 2011; Li *et al*., 2013; Kouwenhoven *et al*., 2002; Zhao *et al*., 2014). With the ever-increasing population, improving rainwater management to mitigate the negative impacts of water deficiency and increase water productivity in semi-arid areas is crucial to ensure future food security (Lin *et al*., 2015). Semi-arid areas experience severe crop yield reductions due to dry spells that occur once or twice in every five years (Rockstrom *et al*., 2002). Conservation tillage practices simultaneously conserve soil and water resources, reduce farm energy usage and increase or stabilise crop production (Mapungwa *et al*., 2007; Zhao *et al*., 2018; Ma *et al*., 2018).

Rain-fed agriculture plays a crucial role for global food supply (Rockstoom *et al*., 2010). Increasing demand of food globally (Zeng *et al*., 2018b; Mueller *et al*., 2012) and water resources shortage are the primary problems encountered in rain-fed agriculture (Zhang *et al*., 2018). Mulching improves infiltration of rainwater into the soil potentially increasing water availability to plants thereby reducing surface runoff and improving groundwater recharge (Lipic *et al*., 2005; Mupangwa *et al*., 2007; Findeling *et a*l., 2003; Rees *et al*., 2002; Ji and Unger, 2001). Conservation of soil moisture is one of the major advantages of the mulch farming system (Mulumba and Lal, 2008). Crop adaptation to rain-fed conditions can be achieved by improved water use efficiency (WUE) or by increasing water supply to the plant through improved root system (Hall, 2004). Large variability in WUE has been reported among several species as well as cultivars within species, including cowpea (Martin *et al*., 1992; Hall *et al*., 1990; Condon *et al*., 2002). Higher rates of leaf photosynthesis are often associated with faster crop growth rates, thus a combination of higher photosynthesis and improved WUE may play a vital role for yield enhancement of crops under drought stress conditions (Parry *et al*., 2005; Condon *et al*., 2002). Mulching, therefore, can help aid in agricultural production in semi-arid regions by retaining water in the soil.

Soil surface mulching is a common and viable practice for offsetting water limitations in agricultural production. Crop response to water stress or water supply varies during different growth stages (Lin *et al*., 2015). Organic mulch adds nutrients to the soil due to microbial activity and it helps in carbon sequestration (Farooqi *et al*., 2018), provides better soil environment by conserving soil moisture and inhibits weed growth in crop fields (Jodaugiene *et al*., 2006). Therefore, mulching is essential for weed control, moisture conservation and the protection of seed beds from erosion during high rainfall which is an important and essential component in cultivation. Mulching also adds organic matter to the soil during the latter part of the cropping season. Thus, agricultural land management practices such as mulching can remarkably influence the success of legumes. Mulching can improve soil water supply to crops through reduced runoff and soil evaporation, increased infiltration and better water storage (Mupangwa *et al*., 2007). Furthermore, mulching avoids the fluctuations in temperature in the first 20-30 cm depth in soils, therefore favouring root development and raising the soil temperature in the planting bed, and thus promoting faster crop development and early harvest (Mundy and Agnew, 2004; Mahajan *et al*., 2007).

Although the beneficial effects of mulching are known, there are instances when its availability is limited. Crop residues have numerous competing uses, for example fodder, fuel and construction material. Similarly, costs are incurred in application and these increase with mulch level. It is therefore necessary that an optimum mulch application rate is established if one is to enhance or maintain high soil quality in a cost-effective manner. Living mulches can be competitive with landscape plants for water, nutrients and space, thus they must be kept away from newly planted shrubs and trees and be replaced with organic mulch. Mulch quality is influenced by the source of materials (Chalker-Scott, 2007). Mulches created from branches and tree trimmings often contain a diversity of leaves, wood and bark, contributing to highly functional mulch. In contrast, woody mulch made from wood recovered from construction and demolition debris can contain pressure-treated lumber and the rapid decomposition of the wood chips could produce excessive heat or create a nitrogen deficiency from increased microbial activity (Harris, 1983; Watson and Kupkowski, 1991). Mulch made from diseased plant material contains pathogens. Mulch that is excessively deep could potentially damage roots by reducing soil aeration. Therefore, organic mulch is preferable.

Simulation models are valuable tools in the analysis of farming systems for assessing the impact of climate variability and long-term scenarios of management strategies (Keating *et al*., 2003). They are complementary to the experimentation, which is invariably constrained by seasonal conditions, the treatment imposed and duration of the experiments. Models are a means of extrapolation of knowledge from experimentation which include crop sequence, tillage, residue and fertilizer management practices. Crop models are classified into three broad categories, namely: statistical, mechanistic and functional models. The Agricultural Production Systems Simulator (APSIM) is defined as a framework that allows individual modules of key components, such as crop cultivar and agricultural practices, of the farming system (defined by model developer and selected by model user) to be modelled (Keating *et al*., 2003; McCown *et al*., 1996). The APSIM model is used in the simulation of discrete management units within production systems. It is a simulation model designed to address long term resource management issues. It resulted from a need for tools that provide accurate information on crop production in relation to climate, genotype, soil and management units within production systems (Seshuhla, 2009).

Balwinder *et al*. (2011) stated that before a model can be used to help determine optimum crop and cropping system management, it must be parameterised and validated for the environment and management practices of interest. Probert *et al*. (1995, 1998) developed the APSIM surface organic matter module which was formerly known as the APSIM-residue and Thorburn *et al*. (2001) described it in detail. The results of Adams *et al*. (1976) can be used to calculate the effect of crop residues on the potential drying rate of soil water. While APSIM includes a generic simulation framework, it can only be applied in situations where the acceptable biophysical modules are available. In this respect, APSIM's capability is most developed for cropping systems, with crop modules available for the bulk of the grain and fibre crops grown in temperate and tropical areas. The APSIM model's strong modular design (Holzworth *et al*., 2014) has made it possible to easily build links to component models developed by other groups.

1.2 Problem statement

Most parts of Limpopo Province in South Africa are semi-arid, characterised by low erratic rainfall and high temperatures. They are prone to drought and soil erosion, which are exacerbated by climate change. In the dry season, stunted growth, poor fruit set and poor yields may occur because of dry soils. Smallholder farmers depend primarily on rain-fed agriculture. However, rainfall is highly variable and unequally distributed in these regions. It is thus crucial to make farmers realize the need to use mulch in conserving soil water in the cropping system, that is, it is necessary to conserve soil moisture to maximize crop yields. Recently, there has been a renewed effort to address the low crop production through the introduction of conservation tillage into production systems. It is thus, important for small scale farmers to adopt water management strategies such as mulching to conserve moisture. Mulch influences the germination and growth performance of cowpea. There is hardly any use of mulch application in the current smallholder farming systems in Limpopo Province. To address these constraints, the APSIM model will be used to validate crop performance under mulch application to assist farmers in making sound decisions. There is need, therefore, to investigate the effects of mulch in relation to the production of cowpea and soil water content under rain-fed conditions in the Vhembe district.

1.3 Justification

Food insecurity is a critical issue in most parts of the world, South Africa, included, especially in rural homesteads. Smallholder agriculture in South Africa can be used as a vehicle which the reduce of poverty and drive rural development can be achieved. Most smallholder farmers in the area depend on nutrients that are naturally produced for crop production under rain-fed agriculture. Cowpea is an under-utilized indigenous crop, which has many advantages for small scale and commercial farmers in the semi-arid parts of Limpopo Province. Cowpea is a source of protein and is drought tolerant, which is a good attribute as these areas have low erratic rainfall and high temperatures. Therefore, ensuring that water is retained in the soil, improving soil water supply to crops through reduced soil evaporation and runoff, increased infiltration and water storage is essential to sustain agricultural production. Thus, boosting crop water use efficiency (making less water produce high yields), is of significance to improve the productivity of rain-fed croplands. It has been proved that mulching improves soil moisture content and decreases weed growth, thereby enhancing yield in vegetable crops. The APSIM model has been proven to simulate crop performance under various management practices (mulching and Intercropping) to assist farmers in making viable decisions. Thus, addition of mulch to the soil can help meet the cowpea demand for water and improve cowpea yield, while the APSIM model can be used to validate crop performance in an area. The benefits of this is to help small-holder farmers to establish whether this crop management practice (mulching) would be beneficial in the future and whether it is sustainable for their area.

1.4 Study Objectives

1.4.1 Overall objective

To determine the effects of mulch application rates on cowpea growth, yield and soil water content and to validate the results using APSIM.

1.4.2 Specific objectives

1. To determine the effects of different rates of mulch application on growth, dry matter and grain yield of cowpea.
2. To evaluate the effects of different rates of mulch application on soil water content at different stages of growth and water use efficiency (WUE) of cowpea.
3. To validate the effect of mulch application rates on growth, grain yield, dry matter and soil water content of cowpea using the APSIM model.

1.5. Study hypotheses

1. Cowpea growth yield and dry matter accumulation will be influenced by mulch application rates.
2. Mulch application rates will influence soil water content and cowpea water use efficiency (WUE).
3. The APSIM model can be used to validate the effects of mulch application rates on cowpea growth, grain yield, dry matter and soil water content with great accuracy.

CHAPTER TWO

2. Literature review

2.1 Cowpea.

Cowpea is one among several species of the widely cultivated genus Vigna. Cowpea is one of the most important food legume crops within the semi-arid tropics which form parts of Asia, Africa, Southern Europe, and Central and South America. A drought-tolerant and warm-weather crop, cowpea is well-adapted to the drier regions of the tropics, where other food legumes do not perform well (Obatolu, 2003). It also has the ability to fix the atmospheric nitrogen through its root nodules, and grows well in poor soils with more than 85% sand and less than 0.2% organic matter and low levels of phosphorus (Singh *et al*., 2003). In addition, it is shade tolerant, hence it is compatible as an intercrop with maize, millet, sorghum, sugarcane and cotton making cowpea crucial to traditional intercropping systems within the variegated and ornate subsistence farming (Ofuso-Amin and Limbani, 2007; Blade and Singh, 1994). The haulm (dried stalk) of cowpea is an essential by-product that is used to feed animals. Cowpea leaves, pea pods and peas are edible, which means before the dried peas are harvested, it can be used as a food source, but it is mostly grown for its edible beans (DAFF, 2011; Ehlers and Halle, 1997).

2.1.1 Importance of Cowpea.

Cowpea is known to be the most economically important indigenous African legume crop (Langyintuo *et al*., 2003). Cowpea is an important source of food for humans in poor arid regions; the crop can also be used as feed for livestock. Cowpea is fed to livestock predominately in India where it is fed as forage or fodder (Singh *et al*., 1997). Cowpea provides a rich source of proteins, calories, minerals and vitamins. The seed of a cowpea contains 25% protein and is low in anti-nutritional factors (Rangel *et al*., 2003). This cowpea diet complements the mainly cereal diet in countries that grow cowpea as a major food crop (Phillips *et al*., 2003).

2.1.2 Climate and soil condition suitable for cowpea growth.

According to DAFF (2011), cowpea grows best during summer (October-March). The minimum temperature for germination is 8.5 °C while the minimum temperature for leaf growth is 20 °C (Ngalamu *et al*., 2014). Cowpea is a heat-resistant and drought-tolerant crop (Van Rensburg *et al*., 2007), but it is also adaptable to cooler and high rainfall areas. It is this excellent adaptability to a wide range of climatic conditions and the presence of many varieties that makes this crop highly suitable for the climate of Limpopo. The temperature for optimum growth and development is about 30 °C (SARI, 2012). Cowpea response to day length differs with varieties, some are insensitive and flower within 30 days after sowing when grown at a temperature of around 30 °C. The time of flowering for photosensitive varieties is dependent on time and location of sowing and may be more than 100 days (DAFF, 2011; SARI, 2012). Even in early flowering varieties, the flowering period can often be extended by warm and moist conditions, resulting in asynchronous maturity. In Limpopo Province, the optimum sowing times are December to January. Crops that are sown early tend to have elongated internodes, lower yields, are less erect and more vegetative than those sown at optimum time. Nodular bacteria specific to cowpea (Bradyrzobium spp.) makes it suited for cultivation in the hot marginal cropping areas, as well as the cooler higher rainfall areas of Southern Africa (DAFF, 2011).

Cowpea is sensitive to waterlogging (Harris *et al*., 2006). The frequency and unreliability of rainfall poses problems to cowpea growth in South Africa (DAFF, 2011). In some areas, the frequency of rain is too high, leading to flooding, while in other areas it is so unreliable that moisture conservation remains vitally important for crop production. Cowpea is often produced satisfactorily with an annual rainfall between 400 and 700 mm (Harris *et al*., 2006). In some areas of Mpumalanga, where annual rainfall is high, cowpea might be planted at a time to coincide with the peak period of rainfall during the vegetative phase or flowering stage to ensure that pod-drying takes place during dry weather (DAFF, 2011). Adequate rainfall is important during the flowering/podding stage. Cowpea reacts to serious moisture stress by limiting growth (especially leaf growth) and reducing leaf area by changing leaf orientation and closing the stomata. Flower and pod abscission during severe moisture stress also function as growth-restricting mechanisms.

Cowpea is grown on a wide range of soils but prefers sandy soils which are less restrictive to root growth (DAFF, 2011; Ngalamu *et al*., 2014). This adaptation to lighter soils (sandy loams and sandy soil) includes drought tolerance through reduced leaf growth, less water loss through stomata, and leaf movement to scale back light and heat load under stress (DAFF, 2011). Good growth requires a soil pH of between 5.6 and 6.0 (Harris *et al*., 2006; Ngalamu *et al*., 2014). Cowpea can survive under infertile acid soils, but it is reported to be less tolerant to cold soils (DAFF, 2011). It is important that the rainfall is well distributed for normal growth and development. Since South Africa is faced with uneven rainfall, this may have negative consequences on cowpea growth and yield.

2.1.3 World production of Cowpea

Most cowpeas are grown on the African continent, particularly in Nigeria and Niger, which account for 66% of the world cowpea production (FAOSTAT, 2015). United States is the only country that is a substantial producer and exporter of cowpea, of the developed countries (Imrie, 2000). Cowpea production areas and production figures for the United States are, however, not well known. Langyintou (2003) reported that in the 1990s Myanmar exported around 30 000 tons annually to India and Middle Eastern Countries and India imported annually some 15 000 to 20 000 tons of cowpea mainly from Myanmar. Since the FAO (Food and Health Organization) stopped publishing cowpea statistics in mid of 1980s, there is no reliable source of international statistics on cowpea production or marketing. Many cowpea scientists need such statistics. Biological scientists need them to explain and justify their programs. Statistics are the essential elements for socio-economic research (Bean/Cowpea CRSP West Africa, Social Science Report April-Sept., 1998). It is estimated that cowpeas are cultivated on 12.5 million hectares and have a worldwide production of 3 million tonnes (DAFF, 2011). Although cowpea plays a key role in subsistence farming and livestock fodder, it is also a major cash crop for Central and West African farmers, with an estimated 200 million people consuming cowpea on a daily basis (Langyintuo, 2003). According to the Food and Agriculture Organisation of the United Nations (FAO), the average cowpea yield in Western Africa in 2012 was estimated to be 483 kg/ha, which is still 50% below the estimated potential production yield (Phillips *et al*., 2003; Kormawa *et al*., 2002). In some traditional cropping methods, the yield can be as low as 100 kg/ha.

2.1.4 Production of Cowpea in South Africa

In Africa, information on cowpea marketing and trade is not sufficient and data on cowpea production economics scattered, because market research has focused on export crops such as cocoa, coffee, cotton, and groundnut and to a lesser extent cereal (Van der Laan cited by Langyinto *et al*., 2003). The two main sources of data are: FAO complemented by the statistical service department of various countries, and information collected by the socioeconomic groups of the Bean/Cowpea CRSP. FAO, however, estimates that 3.3 million tonnes of cowpea dry grain were produced worldwide in 2000. (IITA Research, 2001), but only a small proportion enters international trade. In South Africa, small-scale farmers who are affected by dryland farming conditions are the largest producers of cowpea. However, there are no records of the dimensions of the area under production and therefore quantities produced (DAFF, 2011). Cowpea is grown in the following provinces: Limpopo, Gauteng, Mpumalanga, North West and KwaZulu-Natal (NDA, 2009). Cowpea is one among the most important food security grain legumes in South Africa. However, despite its contribution to rural families' diet, soil fertility and livestock feed, cowpea may be a neglected crop. None availability of adapted high yielding cowpea varieties may be a major constraint to cowpea production in South Africa. Although there are reports of 1.5 t/ha in the Free State province, where it had been believed that cowpea is not well suited, there is not enough information on the area under production. In 2013, 7000 tons of cowpea was produced from 13 500 ha in South Africa. FAOSTAT (2013) also established that South Africa produced 5674 tons of cowpea in the growing seasons of 2011 and 2012. The potential grain yield, under sole cropping is high (1.5 - 3.0 t/ha). However, the farm yields obtained by South African farmers are much lower averaging less than 500 kg/ha (Asiwe 2007, 2009a).

2.1.5 Cowpea production constraints in South Africa

Cowpea production constraints in South Africa include diseases and insect pests. In South Africa, viral and fungal diseases seem to be very important. Other factors limiting cowpea yield include, nematodes, extreme temperatures, low soil fertility, lack of good seed, seedling mortality caused by *Pyfhium* sp., anthracnose caused by *Colletotichum lindemuthianum* (Sacc. and Magn.)., leaf spots caused by *Cercospora* and *Septoria spp*., rust caused by *Uromyces appendiculatus* (Pers) Fries and *Pyfhium* stem rot caused by *Pyfhium aphanidermatum* (Edson) and improved varieties as well as bad cultural practices (Onesirosan and Barker 1971; Bailey *et al*., 1990; Emechebe and Fiorini 1997). Twelve viral diseases that are known to attack cowpea have been identified (ARC, 2018). One of the diseases causing significant losses to stem, pods and leaves of cowpeas is moore (Latunde-Dada *et al*., 1996).

2.2 Mulching

2.2.1 Definition

Mulch is considered as a layer of material (organic or inorganic) applied to the surface of soil spread around or over a plant in order to insulate or enrich the soil (Nalayini 2007; Kader *et al*., 2019). Mulch is applied for several reasons such as soil moisture conservation, improvement of soil health and fertility, reduction of weed growth as well as the enhancement of an area's visual appeal.

2.2.2 Types of mulch

They are two types of mulch, namely, organic and inorganic. Organic mulches include bark, hardwood and softwood chips, newspaper, compost mixes and cardboard and a variety of other plant by-products. Organic mulches consist of materials that decompose over time. When organic mulches are worked into the soil, they can improve soil fertility, structure, aeration and drainage because they decompose (Schwartz, 2019). According to Kasiraian and Ngouajio (2012) cereal straw is the most common organic mulching material. Natural mulches do not always provide adequate weed control because they may carry weed seeds and often retard soil warming in spring. Straw mulches deplete the seedbed nitrogen due to their high carbon-to-nitrogen ratio (Kasirajan and Ngouajio, 2012) and they may carry weed seeds). Replenishment on a regular basis is necessary for organic mulches because they decompose. Inorganic mulches bring many benefits to the soil. These include several types of materials that do not decompose and thus do not need replenishment very often, if ever. Inorganic materials include rock, stone, crusher dust, landscape fabrics and many more man-made materials. Inorganic mulches are ideal for controlling weeds and decorative uses. Since rocks and stones reflect and absorb moisture, they warm the soil for early spring planting of fruits and vegetables but can be detrimental to plants during periods of hot and dry weather (Schwartz, 2019). Hay mulch is ideal for mulching newly seeded soil. Hay mulch keeps the soil from washing away. It is also known to deter birds and rodents. Hay mulch conserves the moisture that the seeds need for germination, that is, until it decomposes. Natural mulches reduce soil temperature and evaporation (Kader *et al*., 2017b: Subrahmaniyan and Zhou, 2008).

2.2.3 Benefits of mulching

The presence of crop residue mulch at the soil-atmosphere has a direct influence on infiltration of rainwater into the soil and evaporation from the soil (Mupangwa *et al*., 2007). Mulch cover reduces surface runoff and holds rainwater at the soil surface, thereby giving it more time to infiltrate the soil (Mupangwa *et al*., 2007). Mulches are also known to promote crop development and early harvest, as well as increase yields. Ossom *et al*. (2001) reported that very little weed growth occurs under the mulches as they prevent the penetration of light or exclude certain wavelengths of light that are needed for the weed seedlings to grow. Mulches greatly retard the loss of moisture from the soil by reducing evapotranspiration (Mupangwa *et al*., 2007).

2.2.4 Disadvantages of mulching

Heavy mulching over a period of years may end in a build-up of soil over the crown area of plants. Some mulch material can be costly and not readily available, which can be a drawback to small- and large-scale mulching. Also, when using sawdust and woodchips as mulch, nitrogen starvation sometimes occurs (Jalota and Prihri, 1998). Some mulch material (twigs and straw) attract some type of pests, according to the type of padding. In the case of plastic mulch, some beneficial plants such as trebol disappear. In some types of mulch, like that of straw, when it is fresh, it can germinate its seeds and become weeds. Straw, herbs or leaves can attract rodents (Solomon, 2010). Long-term plastic film mulch has a huge negative impact (Wang *et al*., 2009; Zhang *et al*., 2008; Hou *et al*., 2010), causing deterioration of soil structure, crop root entanglement, nutrients and water inhibition, which affects root development, reduces crop yields and restrains the sustainable development of agriculture (Liu *et al*., 2014; Gu *et al*., 2017). Mulch can also delay crop growth and development which can increase crop water use after anthesis. Mulch induced reduction in grain yield tends to nullify its positive effects through water conservation (Balwinder *et al*., 2011; Chen *et al*., 2007).

2.2.5 Mulching effects on soil water content.

Mulching effect on moisture conservation and ability to increase productivity of crops has been reported in maize (Zhang *et al*., 2005), wheat (Verma and Acharya, 2004a, Verma and Acharya 2004b, Li *et al*., 2005, Haung *et al*., 2005, Rahman *et al*., 2005) and other crops (Tariq *et al*., 2001, Kumar *et al*., 2003, Haq, 2000, Kar and Singh, 2004). Mulching and soil water content (SWC) have a significant impact on soil erosion. Mulch addition to the soil increases the water holding capacity of the soil, thus increasing the soil water content. Mulching affects crop performance by distorting soil conditions such as soil temperature, soil moisture and by also controlling weeds. Mulch reduces soil water evaporation by covering the soil and thus, increasing soil moisture (Seshuhla, 2009; Zhao *et al*., 2018; Ma *et al*., 2018). Tan *et al*. (2014) conducted a field plot study where soil moisture in mulched plots was higher than in un-mulched plots. Zhai *et al*. (2008) observed the same scenario in a cucumber study while Ramakrishma *et al*. (2006) reported increased soil moisture in the straw mulched than un-mulched plots in a study conducted in Vietnam.

Teame *et al*. (2017) found that the analysis of variance revealed that soil moisture content is highly influenced by mulching treatment in all soil depths during the cropping season. They noted that in the upper soil depth (0.02 m) the highest soil moisture (37.9, 37.6 and 36.6% was conserved in all the mulched plots. Al-Rawahly *et al*. (2011) conducted a study on mulching material effect on yield, soil moisture and salinity. They found that more moisture percentage was recorded in soil covered with mulches compared to bare soil surface. Date palm residue was observed to have the highest average soil moisture of 16.55%. They also noted significant differences between different types of mulches, depth and individual interactions. The highest average of soil moisture was at depth 45 cm with a percentage of 16.17.

Rathore *et al*. (1998) observed that more water was conserved within the soil profile during the early growth period with straw mulch than without it. Similar findings were found by Rahman *et al*. (2005) and Chackraborty *et al*. (2008). Rathore *et al*. (1998) also noted subsequent uptake of conserved soil moisture and soil mechanical resistance, leading to better growth and higher grain yields. According to trials conducted by Erenstein (2002) in the higher potential areas of Zimbabwe between 1988 and 1995, mulching indicated significantly reduced surface runoff and soil loss, meaning that mulch application is essential in semi-arid areas prone to soil erosion. Mulch cover shields the soil from radiation from the sun, thereby reducing evaporation from the soil. Bunna *et al*. (2011) reported higher soil water content in the mulch treatments (13.6% versus 12.4%).

2.2.6 Effects of mulch application rates on yield

According to Raju (2013) and Chen *et al*. (2019), the application of mulch under water-limited and warm environments usually increases crop yield due to reduced temperature and increased retention. The increase in yield is also supported by studies conducted by Ramakrishna *et al.* (2006) where a higher yield was observed in mulched than in un-mulched plots. Grain yield of well-managed dryland cowpea ranged between 1.0 and 4.5 Mg/ha and reached 6.0 Mg/ha under irrigation in California (Fery, 1990). Total dry matter and grain yield of cowpea were found to be linearly related to seasonal water use (Turk and Hall, 1980; Pandey *et al*., 1984). In semi-arid regions, mulching can significantly improve soil water content and temperatures, ensure crop water supply, thus promoting the photosynthetic capacity of crop leaves and resulting in significant increases in crop primary productivity (Hou *et al*., 2015; Lui *et al*., 2010; Mo *et al*., 2018). In an experiment done on soybean and different mulching treatments by Kader *et al*, (2017), soybean seed yield increased under mulching treatments compared to the bare soil. Increased soybean yield under mulching was also reported by Arora *et al.* (2011) and Sekhon *et al*. (2005).

A field trial conducted by Mupangwa *et al*. (2012) over four seasons with three tillage methods (reduced tillage, mulching and crop rotation) showed that mulching improved cowpea yields in seasons that had poorly distributed rainfall with 2 and 4 t/ha giving similar yields. The study showed that higher mulch levels of 8 and 10 t/ha, which were under the smallholder conditions at the time, suppressed cowpea establishment, which means that they should not be recommended. An experiment conducted by Mupangwa *et al*. (2007), showed that under different tillage treatments, 4 and 10 t/ha mulch cover maintained higher profile water content especially during dry spells thus increasing crop yield. Mupangwa *et al*. (2012) reported that mulching improved maize yields. Although the highest maize yields were achieved at 8 t/ha mulch rate, there were no significant yield benefits derived from increasing mulch cover beyond 4 t/ha. Bunna *et al*. (2011) reported that among all their treatments, mulch had the largest and most consistent positive effects on crop establishment and yield. Mulch improved crop establishment by about 10% in all locations with mean 72.22 and 83.1% for no mulch and mulch, respectively. In the same experiment, mulch increased grain yield by between 77 and 80%. In a field experiment by Ncube *et al.* (2007) conducted on the productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south-western Zimbabwe, it was reported that cowpea produced the highest grain yields during the dry 2002/03 cropping season. In the winter of 2003/04 cropping season, the cowpea crops were severely attacked by aphids, resulting in poor grain yield. The third season of 2004/05 resulted in cowpea producing an average of 0.35-0.46 t/ha.

2.2.7 Mulching effects on water use and water use efficiency

Water use efficiency (WUE) is the total yield obtained from water available to the crop through rainfall, irrigation, runoff, drainage and the contribution of the soil water storage. Maximum agricultural production, especially in low rainfall cropping systems in the tropics and sub-tropics, is greatly affected by water utilization and uptake (Ogola *et al.*, 2009). In an experiment conducted by Chimonyo *et al*. (2016), WUE calculated using total biomass (WUE_b) varied across seasons, water regimes and cropping systems. Though not statistically significant, WUE calculated using yield (WUE_g) also varied across seasons, water regimes and cropping systems. Fan *et al*. (2017) indicated that plastic mulch accelerated plant growth, advanced maize maturity, increased yield and WUE in maize field.

Li *et al*. (2016) conducted an experiment with four treatments: flat planting without film mulch (CK), flat planting with film mulching (M1), ridge-furrow planting with film mulch on both ridges and furrows (M2) and ridge-furrow planting with film mulching on continuous ridges (M3). The author reported that soil water storage after harvesting did not differ significantly between M1 and M2 but was significantly higher in M1 and M2 than in CK and significantly lower than in M3. Evapotranspiration was recorded to be at its lowest in M3 and the highest in CK in three growing seasons. The experiment showed that ET did not differ markedly between M1 and M2 in the first season but was significantly lower in M2 than in M1 for the second season. Mean ET for the three growing seasons was 23.6, 14.3, and 9.4% lower in M3 than CK, M1 and M2, respectively. Water use efficiency was significantly higher in M3 than in CK, M1 and M2 by 155.3 and 78.5 respectively and 33.4% in the first season; 101.7 and 53.8, respectively, and 22.4% for the second season.

In an experiment conducted in Texas by Moroke *et al*. (2011), it had been noted that cowpea crop water use was lower compared with other dryland studies within the region. This is as a result of the limited precipitation received during the growing season. Low water use of cowpea is said to be related to the limited rooting depth. Chen *et al*. (2019) noted that straw strip mulch improved water use efficiency and the yield of potato in rain-fed semi-arid areas. In a study by Miriti *et al*. (2012), crop water use efficiencies were highest in the short rain season than in the long rain season for both grain and total dry matter water use efficiency. Grain and total dry matter WUE for maize and cowpea were greatest in the short rain season of 2007 and 2009 because of better rainfall distribution and crop yields in both seasons. Lower WUE was observed in the short and long rain seasons of 2008 due to smaller yields resulting from poor rainfall distribution. The short rain season of 2008 had the highest amount of rainfall yet had the lowest WUE. This clearly demonstrates that rainfall distribution is of great importance in obtaining good crop water use. Significant amounts of water in the short rain season of 2008 could have been lost as runoff as it rained within a week in high intensity (46 mm/day).

2.3 APSIM model for agricultural research

Simulation models are known to increase the advantages of using mulch in cowpea in different climates; therefore, they have been tested in cowpea systems for their ability to simulate the impacts of mulching. The APSIM model has been tested extensively in Australia to predict yields of sorghum, forage, pasture and grain legumes (Ncube *et al*., 2007). Literature evidence shows that the APSIM model has the ability to simulate productivity and resource use in intercrop systems (Dimes *et al.,* 2011; Knorzer and Lawes, 2011; Robertson *et al*., 2004). Ncube *et al*. (2009) conducted a field study where the model was used to predict grain yield of legume crops across three seasons. The model generally showed good prediction of total biomass and grain yields of the legumes in all three cropping seasons, providing evidence that APSIM captured the effects of variable water supply on crop production in very wet and very dry seasons quite well. There was an equally good performance in total biomass (RMSE = 643 kg/ha, R^2 = 0.65) and grain (RMSE= 221, R^2 = 0.79) prediction, which was indicative that total biomass accumulation and partitioning to grain was well simulated by legume crop modules under those range of conditions.

Chimonyo *et al*. (2016) noted that model simulation for sorghum yield was satisfactory as indicated by low RMSE (82.7 kg/ha) with a 7% difference from observed yield. On the other hand, the authors noted that model simulation for cowpea yield was spoor, (RMSE = 44.8 kg/ha) with an overestimation of 31%. In an experiment conducted by MacCarthy *et al*. (2009) on a homestead and a bush farm, the APSIM module predicted the trend of total biomass production under various treatment combinations. There was also a good interrelation between the observed and predicted total dry biomass values (r=0.86). Therefore, the model's performance in predicting total biomass was good, with an internal model efficiency coefficient of 0.50, RMSE of 1.17 t/ha and MdUAPE values of 28 to 44%, respectively. MacCarthy *et al*. (2009) observed a lower RMSE grain yield prediction in the homestead than that in the bush farm. A study by Chimonyo *et al*. (2016) indicated that the APSIM model was able to simulate sorghum-cowpea intercrop systems under different water regimes. The model was able to give reliable simulations of biomass, yield, phenology and crop water use for both sorghum and cowpea under different water regimes. Simulations of biomass yield and WU for sorghum-cowpea under rain-fed conditions were overestimated and this resulted in a reduction of calculated WUE. The model was limited in its ability to simulate under rain-fed conditions. Improvements in the model's performance can be enhanced if it is able to capture extreme weather events.

CHAPTER THREE

3. Materials and Methods

3.1 Experimental site

Field experiments were conducted at the University of Venda experimental farm, (30° 26'' 441' E and 22° 58'' 081' S), situated in Vhembe district, Limpopo Province. The experiment was conducted over two seasons (2016/17 and 2017/18). The experimental farm is in a semi-arid area in Vhembe district. The annual rainfall at the farm is highly seasonal, with 85% occurring in summer, between October and March. A large variability in the rainfall pattern at the farm over a 23-year period was reported by Mzezewa *et al*. (2010). The evaporative demand highly occurs during the summer period with mean maximum temperatures (T_{max}) at 30° C and mean minimum temperature (T_{min}) at 20° C. The long-term monthly rainfall and temperature for the experimental site are presented in Table 1. Soil at the site is classified as Hutton form according to the South African System (Soil Classification Working Group, 1991). Meteorological data were recorded in both seasons by an automatic weather station located within 100 m of the experimental plots. Sowing date for the first season was the 15 of November 2016 and for the second season was the 22 of November 2017. Harvesting was done on the 13 March 2017 and 21 March 2018, respectively.

Table 1: A long-term (50 years) climatic data (rainfall and temperature) averages at University of Venda, Thohoyandou during the period of the growing seasons.

	Oct	Nov	Dec	Jan	Feb
Temperature_{max} (°C)	29	30	30	30	30
Temperature_{min} (°C)	15	17	18	18	18
Rainfall (mm)	61	118	114	164	134

Source: National Oceanic and Atmospheric Administration (NOAA).

3.2 Characterization of soil

3.2.1 Determination of soil chemical properties

Twenty sub-soil samples were randomly collected at the experimental site from 0-20 cm soil depth using a soil auger. The sub-samples were then mixed and bulked together to obtain a composite sample. The composite sample was air-dried and sieved through a 2 mm sieve for analysis of soil chemical properties. The following selected chemical properties were determined; organic carbon content, which was determined using the Walkely and Black method (Nelson and Somers, 1982) and selected exchangeable cations (Mg^{2+}, K^+ and Ca^{2+}) were determined using the ammonium acetate extraction procedure (Peech, 1965). Available P was extracted using the Bray 1 method (Bray and Kurtz, 1945). Total nitrogen was determined using the Kjedahl method (Bremmer and Mulvaney, 1982). Soil pH was determined in 1:2.5 ratio of soil: water.

3.2.2 Determination of soil physical properties

The bulk density (BD) was determined using the core method (Blake and Hartge, 1986). Bulk density was calculated using equation (1):

$$BD\ (g/cm^3) = (WD) / V \quad \text{……………………………………………………………….. (1)}$$

where WD= dry weight of soil (g); V (cm^3) = Volume of the cylindrical core

The following soil physical properties were determined using soil samples from section 3.2.1: texture and porosity. Soil texture was determined using a hydrometer method (Bouyoucos, 1962).

Porosity was determined using equation (2):

$$\text{Porosity} = 1 - Db / Dp \quad \text{………………………………………………………………… (2)}$$

where Db = bulk density; Dp = particle density, assuming a particle density of 2.65 g/cm^3 (Brady and Weil, 2008).

3.3 Characterization of mulch material

The mulch material used was hay. It was chosen because it is easily accessible, inexpensive and is organic and not living. For this reason, it did not compete with the plants for water, nutrients and space.

3.4 Experimental Design

The experiment was conducted over two seasons (2016/17 and 2017/18), with individual plot sizes of 3 m x 3 m replicated four times. Each plot had an inter-row spacing of 90 cm and intra row spacing of 20 cm. The experiment was set up in a Randomised Completely Block Design (RCBD). The treatments consisted of four levels of mulch (0, 2, 4 and 8 t/ha). These four levels were selected because according to literature review anything above 8t/ha supresses crop establishment as well as considering the price of mulch in order to cater to farmer needs based on their resources.

3.5 Cultural practices

Individual plots were ploughed using a tractor and prepared and demarcated manually with a 100 m measuring tape, hand hoes and strings. Cowpea seeds were sown manually to a depth of 2 cm. After sowing, mulch was applied according to the treatments (0, 2, 4 and 8 t/ha). Phosphorus fertilizer (NPK) was applied at 100 kgP/ha, at sowing. Two seeds were sown and thinned to one after emergence to maintain the desired plant population. Supplemental irrigation was applied using sprinkler irrigation system, when necessary, based on soil moisture content determined using neutron probe. The experimental units were kept free of weeds throughout the growing seasons by manual weeding using hand hoes.

3.6 Data collection

3.6.1 Plant material sampling

The following selected variables were measured during plant growth: above ground dry matter at flowering (4 January 2017 and 11 January 2018, respectively) and at harvest maturity, yield and yield components at harvest maturity.

3.6.1.1 Dry matter (DM) accumulation

Dry matter was collected from each treatment by sampling six plants per plot at flowering (4 January 2017 and 11 January 2018, respectively) and twelve plants per plot at harvest maturity (13 March 2017 and 21 March 2018, respectively). The samples were dried at 65˚ C for 48 hours, that is, until a constant weight was attained in an air-forced oven. The samples were weighed to determine DM yield.

3.6.1.2 Yield and yield components

At harvest maturity, twelve plants were sampled from the inner rows in each plot, in each season. Yield and yield components were determined by measuring the number of pods per plant, pod weight, the number of grains per pod and grain weight. Plant pods were separated from the plant manually. The pods were then threshed by hand and the number of seeds per pod were determined. The plants were dried without the pods at 65˚ C for 48 hours to obtain the total dry weight. The same plants that were used for dry matter at harvest maturity were used to determine grain yield and yield components. The seeds were then air-dried and weighed to determine grain yield (kg/ha).

3.6.2 Crop water use and water use efficiency

Soil moisture content was measured on a weekly basis using a neutron probe. Soil moisture was measured at 30, 60 and 90 cm depths. Measurements were taken from emergence until harvest maturity in both experiments. In each season, access tubes were installed to a depth of 1.2 m in each plot. During each measurement, the probes were lowered in access tubes inserted before sowing at a frequency of one access tube per plot. Total crop evapotranspiration (ET) was estimated using the standard water balance equation (3) as described by Howell *et al*. (1995):

$$ET\ (mm) = \Delta S + (P+I)-D-R \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where ET is the crop evapotranspiration (mm), ΔS is the change in soil moisture storage (mm); P-rainfall/precipitation (mm); I-irrigation (mm); D-drainage and R-run-off (mm). Thereafter, WUE was calculated as the ratio of crop total dry matter or grain yield to total crop water using equation (4):

$$WUE = \text{Total Dry Matter} / ET \text{ and } WUE = \text{Grain Yield} / ET \quad \ldots\ldots\ldots\ldots \quad (4)$$

3.7 Determination of parameters used in APSIM

Soil parameters determined for use in APSIM included bulk density (BD), drained upper limit (DUL), crop lower limit (CLL) and the initial soil water content. The initial soil water content was determined using the neutron probe. Parameters influencing soil fertility are mainly represented in APSIM-SoilN2 module. Initial stage variables such as soil organic carbon and soil nitrogen were measured and used for simulations. Parameterization of soil P was obtained by measuring soil P. The bulk density was also measured as indicated in subsection 3.3.2.

The DUL was calculated by multiplying the soil water content with the bulk density and the crop lower limit was determined using the same method used to calculate DUL. The only difference between the DUL and CLL was the water content. The weather data were downloaded from the weather station at the University of Venda. The weather parameters were evapotranspiration, daily temperature and maximum rainfall.

3.8 Simulation set-up

Key APSIM modules used in the study are Cowpea, SoilN2 (soil nitrogen), SoilP (soil phosphorus), SoilWat (soil water) and RESIDUE2. Field management data and the climate of the experimental were required by APSIM. The University of Venda weather data (daily temperature and rainfall) were obtained from the weather station installed by ARC-ISCW at the university. The calculated BD, DUL and CLL content were entered in the APSIM soil window. Soil water content measured, defined the initial soil water content before sowing. All soil water characteristics were measured from the study site. Conceptual soil organic carbon pool is represented as bulk soil organic matter (HUM), soil microbial biomass (BIOM) and fresh organic matter (FOM) in the module. HUM was used because it is the most stable. Management data such as sowing date, sowing depth, mulch application date and method were entered in the manager window in the APSIM model. The initial water content was set into the APSIM data base. The cultivar used in APSIM for all the seasons was banjo.

3.9 Statistical analysis

Analysis was done using the RCBD model; analysis of variances was conducted using the general linear model (GLM) procedure of SAS software version 9.4 package (SAS, Institute, 2013). The effect of mulch application rates on dry matter, yield, soil water content and water use efficiency were analysed using ANOVA. Where significant differences between treatments were observed, mean separation was done using LSD test at ($p \leq 0.05$). The performance of APSIM model in predicting grain yield was evaluated using the root mean square error (RMSE), the median unbiased absolute percentage error (MdUAPE), the root mean square deviation (RMSD) and the modified coefficient of efficiency:

$$\text{RMSE}= [n^{-1} \sum (P_i - O_i)^2]^{0.5} \quad \ldots\ldots \quad (5)$$

where O is the observed yield, P the predicted yield and n is the number of observations.

MdUAPE avoids problems such as bias in favour of lower predictions that occur when using the regular MdAPE (which does not use absolute differences between simulated and observed data) in expressing goodness of fit between predictions and observations (Armstrong and Collopy, 1992).

$$\text{MdUAPE} = 100\ ^{x}\ \text{median}\ [(P_i - O_i) / 0.5\ (O_i + P_i)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6\ )$$

Modified coefficient of efficiency (E_1):

$$E_i = 1 - \frac{\sum_{i-1}^{n}(O-P)^2}{\sum_{i=1}^{n}(O-\acute{O})^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

where O is the observed yield, P the predicted yield and n is the number of observations (Nash and Sutcliffe, 1970).

CHAPTER FOUR

4. Results and discussion

4.1 Weather data

Figures 1 and 2 represent the summary of rainfall and temperatures during the growing seasons, the mean seasonal temperature and rainfall. The rainfall distribution and amount in both cropping seasons differed significantly, with the first season (2016/217) having a higher rainfall amount than that of the second season (2017/2018). In the 2016/17 season rainfall amounts were above normal than the 2017/18 season. The highest amount of rainfall was recorded during the months of December and January for the 2016/17 cropping season. Poor distribution and amount of rainfall in the 2017/18 season affected the growth of cowpea negatively, while the 2016/17 season was negatively impacted by flooding and waterlogging. The highest rainfall during the growing season in 2017/18 occurred in December and February. The month with the least amount of rainfall was October in the 2016/17 season and January in the 2017/18 season.

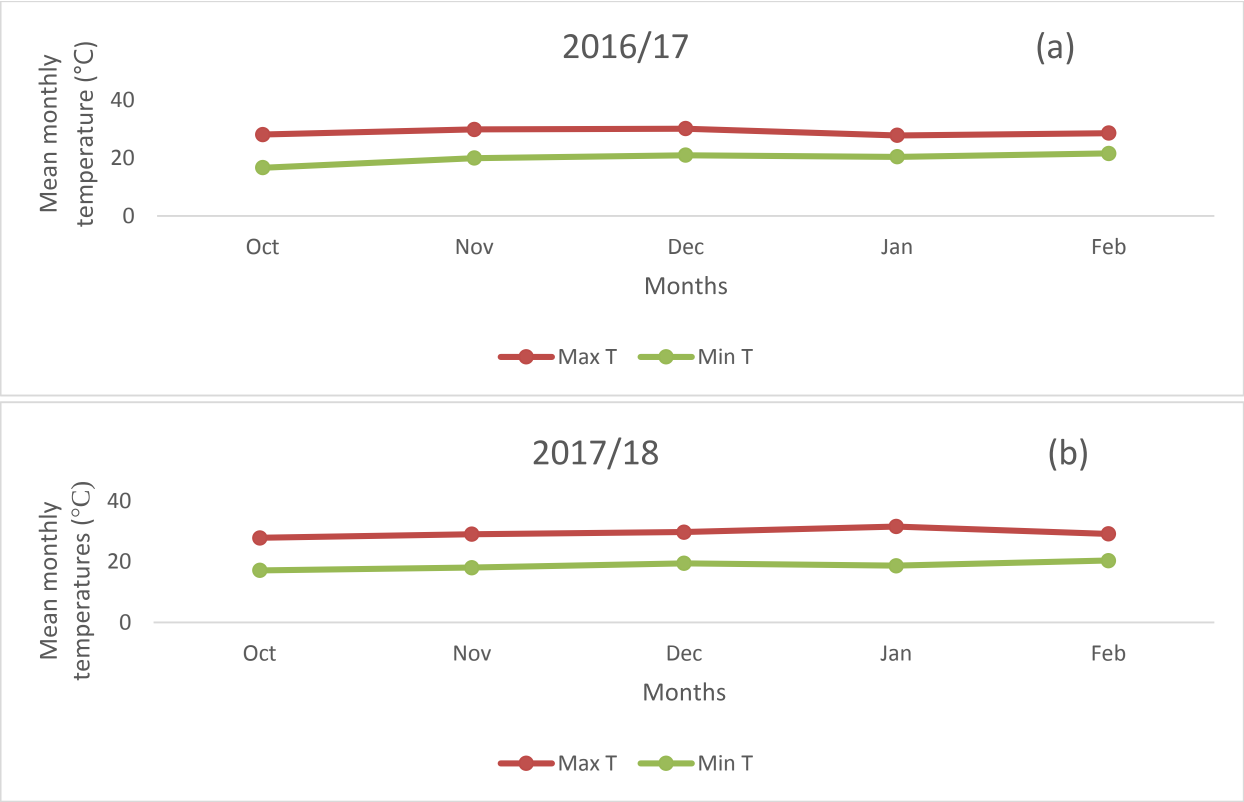


Figure 1: Monthly temperatures in Thohoyandou for the 2016/17(a) and 2017/18(b) season.

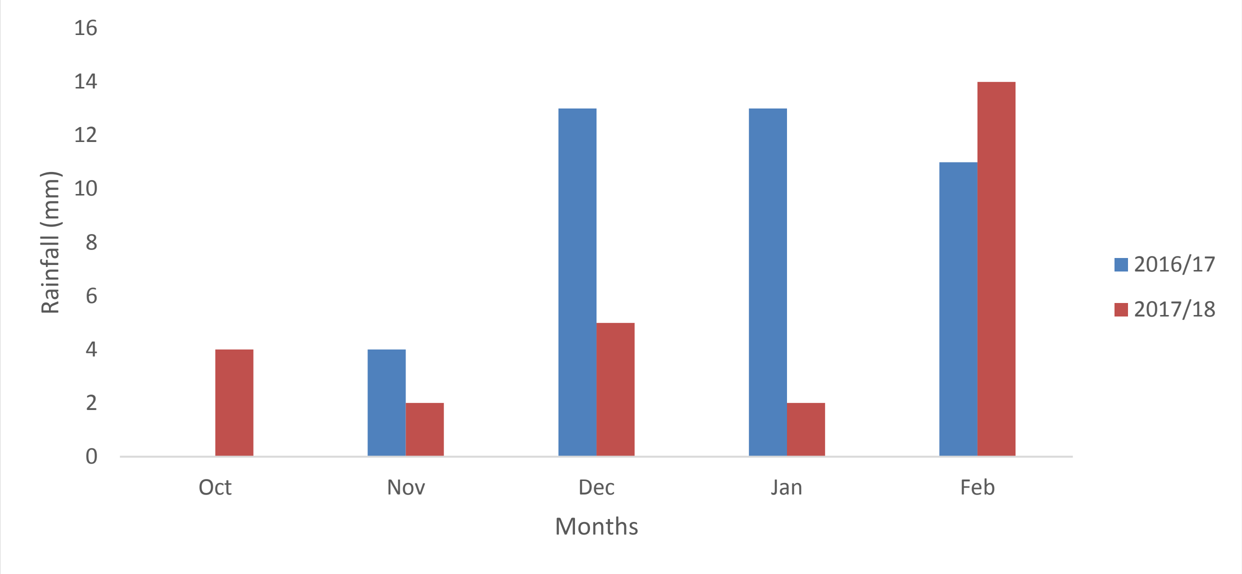


Figure 2: Total monthly rainfall in 2016/17 and 2017/18 cropping seasons.

4.2 Effects of mulch application rates on dry matter at flowering stage and harvesting stage.

Mulch application rate had no significant effect on cowpea dry matter at flowering stage (p<0.5), although the highest dry matter produced was at 8 t/ha mulch application rate with the 2016/17 season having 331 kg/ha and the 2017/18 having 365 kg/ha (Table 2). Less amount dry matter of cowpea was recorded at 0 t/ha mulch application rate, (245 kg/ha 2016/17 and 178 kg/ha 21017/18). The low dry matter at flowering could be due to water stress due to insufficient rainfall in the first four weeks of the growth stage.

There were no significant differences among the treatments in terms of dry matter at harvesting stage, although the highest cowpea dry matter yields were achieved at 8 t/ha mulch application rate in both the 2016/17 and 2017/18 seasons (11144 kg/ha and 9706 kg/ha), respectively. There were no significant yield benefits derived from increasing mulch cover beyond the 4 t/ha mulch application rate and this could be attributed to the amount of rainfall received. The mulched treatments consequently increased total biomass than the unmulched plots but were not significantly different (Table 2). Feng *et al*. (2019) found similar results. Cowpea biomass was generally higher during the first season (2016/17) than the second season (2017/18) because of the higher amount of rainfall (Figure 2). The final biomass observed in both seasons was consistent with observed growth patterns within each growing period.

Table 2: Dry matter of cowpea at flowering stage and harvesting stage as influenced by mulch application rates during 2016/17 and 2017/18.

	Dry matter (kg/ha)			
	Flowering stage		Harvest	
Mulch Application rate (t/ha)	2016/17 (kg/ha)	2017/18 (kg/ha)	2016/17 (kg/ha)	2017/18 (kg/ha)
0	245^a	178^a	8411^a	7793^a
2	261^a	257^a	9303^a	7629^a
4	309^a	344^a	9976^a	8691^a
8	331^a	365^a	11144^a	9706^a
p-value$_{(0.05)}$	Ns	ns	Ns	ns
CV	25.35	22.91	23.68	22.03

Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ns = Not significant, CV= Coefficient of variation.

4.3 Effect of mulch application rates on cowpea grain yield.

There were significant differences among the treatments in grain yield (Table 3). The control had the least grain yield, with (2049 kg/ha) in the first season and (1291 kg/ha) in the second season, while the 8 t/ha mulch application rate had the highest grain yield (3631.20 kg/ha) in the 2016/17 season and 3594 kg/ha in 2017/18 season. The 2 t/ha and 4 t/ha mulch application rate were not significantly different from each other. The differences in yield between the seasons, though not significant, can be attributed partly to the rainfall amount as well as its distribution (Zhang *et al.,* 2017). Previous studies have shown that mulch application can affect soil water content, yield and evapotranspiration, thereby, modifying the crop yield (Chen *et al*., 2015; Rashid *et al*., 2019). In this study, grain yields were higher in the wetter growth season than drier growth season (2017/18) (Table 3 and Figure 2). Similar findings were obtained by Yan *et al*. (2018) with straw mulch and winter wheat.

Observations showed that cowpea yield was affected negatively because of moisture stress and high temperatures during the initial stages of growth in both seasons of the experiment, that is, moisture stress symptoms such as leaf curl and wilt were observed in the un-mulched plots of cowpea during the initial growth stages. There were no visible effects of moisture stress observed on the mulched cowpea leaves. The relative increase in the yield due to mulching was higher in the first season (2016/17) than in the second season (2017/18). This could be attributed to evaporative demand being higher, subjecting the plants under control to more water stress than the mulched plants (Zhang *et al.*, 2009). The improvement in the yield because of mulching over control can be attributed to improved moisture availability to the plants because of lesser evapotranspiration (Adeboye *et al.*, 2017). The yield attributes of cowpea varied under different mulching treatments due to variation in mulch application rates and moisture, both of which modified soil water consumption rates (Kader *et al*., 2017). Practices such as mulching substantially enhance water use efficiency, thus maintaining or even increasing grain yield of cowpea.

Table 3: Effect of mulch application rates on cowpea grain yield.

Mulch Application Rate (t/ha)	2016/17 (kg/ha)	2017/18 (kg/ha)
0	2049^{a}	1291^{a}
2	2233^{ab}	1774^{ab}
4	3341^{ab}	2965^{bc}
8	3631^{b}	3594^{c}
p-value$_{(0.05)}$	*	*
CV	24.42	24.57

Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ns = Not significant, CV=Coefficient variation.

4.4 Effect of mulch application rates on soil water content.

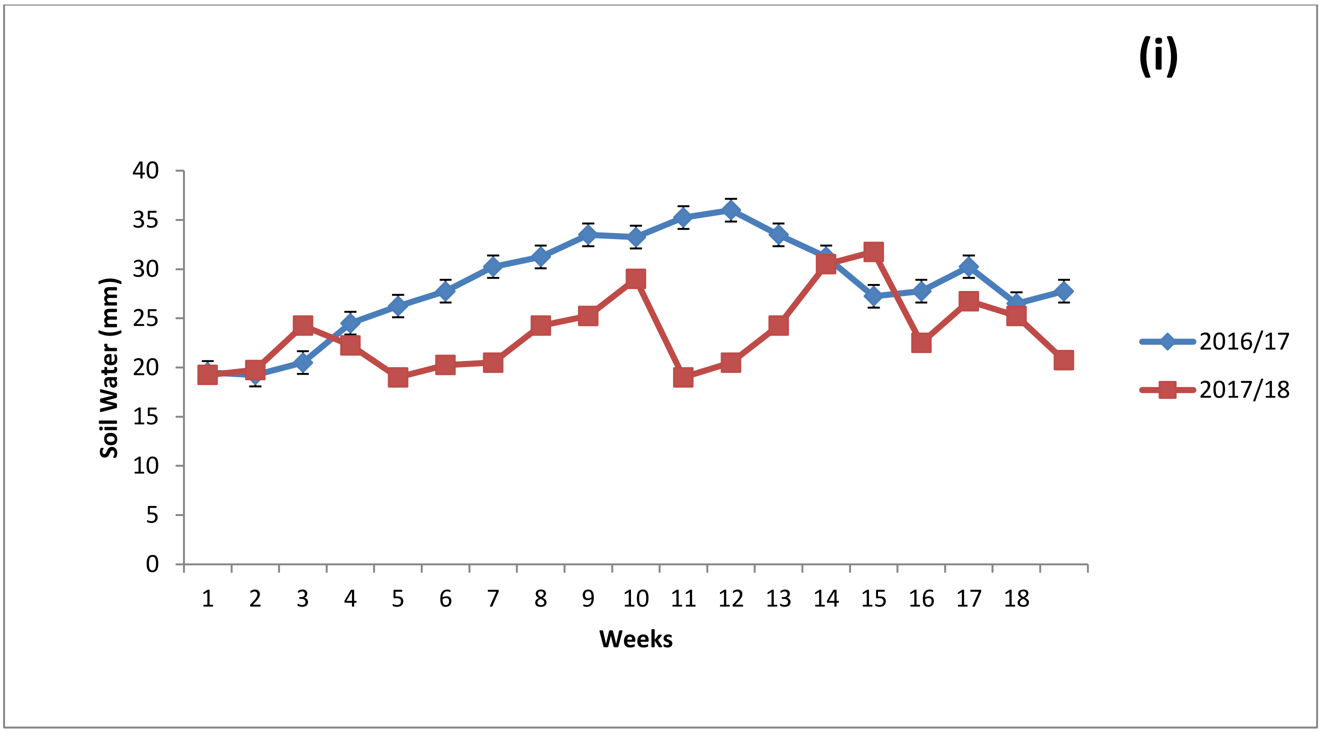
Soil moisture content in the cowpea plots under the different mulch application rates fluctuated with rainfall throughout the cropping season, with the unmulched plots exhibiting a greater fluctuation of soil moisture content (Table 3). There were significant differences among the treatments in the 2017/18 season (Table 4). There were no significant differences in the 2016/17 season. Soil water content was generally higher in the 2016/17 cropping season amongst all the treatments, with 8 t/ha mulch application rate having an average of (32.21 mm) in the 2016/17 season and (28.15 mm) in the 2017/18 season. Plots that had 4 t/ha and 8 t/ha mulch cover showed a discernible difference in soil water content across seasons (Figure 3 a, b, c). Similar findings were reported by Kumar and Dey (2011). Soil water content was highest in December 2016/2017 cropping season due to greater rainfall but decreased in March due to limited rainfall (Figure 3a, b, c and Table 4). The soil water content at different soil depths (0-30, 30-60 and 60-90 cm) and mulch application rates (0, 2, 4 and 8 t/ha) are shown in Figure 3a, b, c.

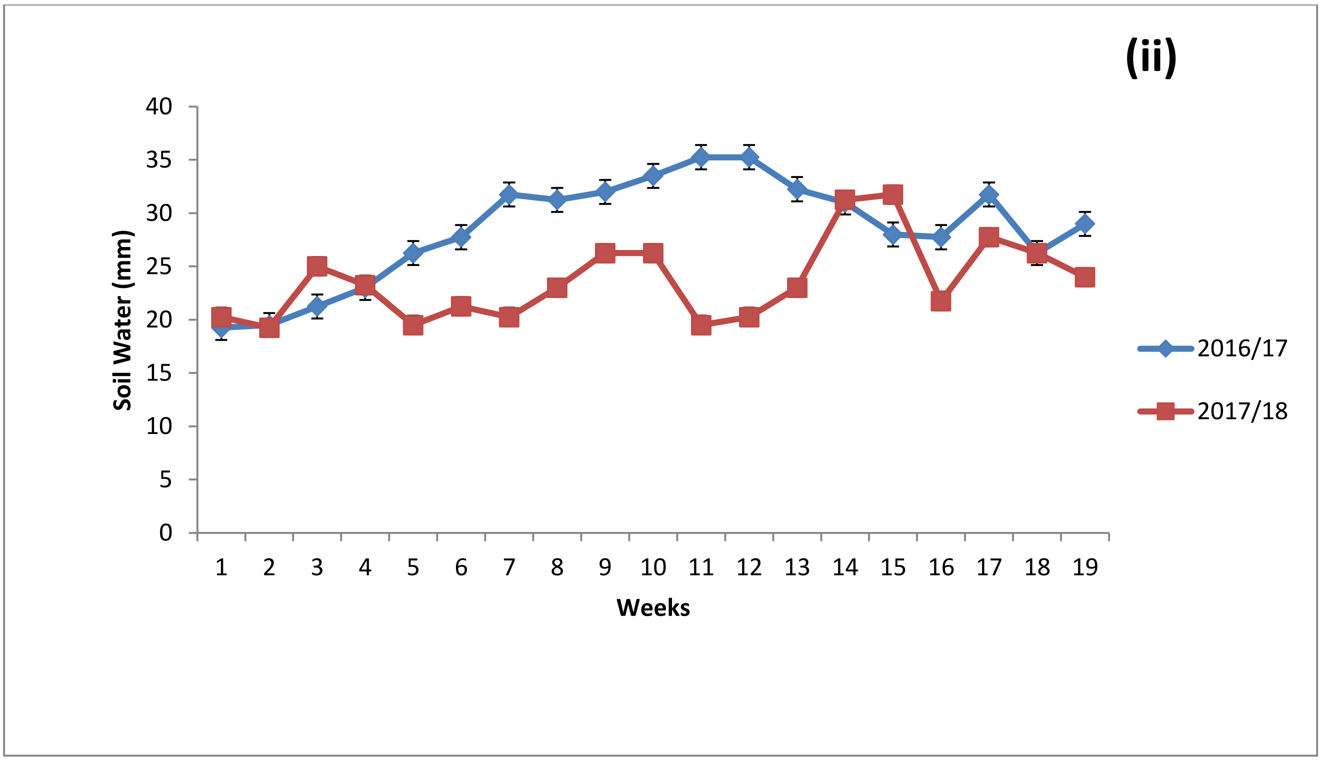
Under the four mulch treatments, 4 t/ha and 8 t/ha mulch application rate maintained higher profile water content during dry spells, especially in the second season (2017/18). The two mulch treatments could have reduced soil evapotranspiration during the dry periods. The soil moisture content was the highest in the first season (2016/17) especially during the months of December and January but decreased in the second season (2017/18) due to limited rainfall and higher temperatures (Figure 1 and 2). The daily moisture content, at 0-30 cm depth was the maximum under the mulched plots and minimum on the unmulched plots. The applied mulch protected the underlying soil from incoming solar radiation and kept the soil cooler than the unmulched plots. The low sensible heat in the mulched plots reduced soil temperature and greater latent heat enhanced soil water content. Due to unrestricted and high surface evaporation the soil moisture content, at 0-30 cm depth in unmulched plots was lower and soil water content was higher than in the other treatments (Döring *et al*, 2005: Zhang *et al*, 2017: Diaz *et al*, 2005).

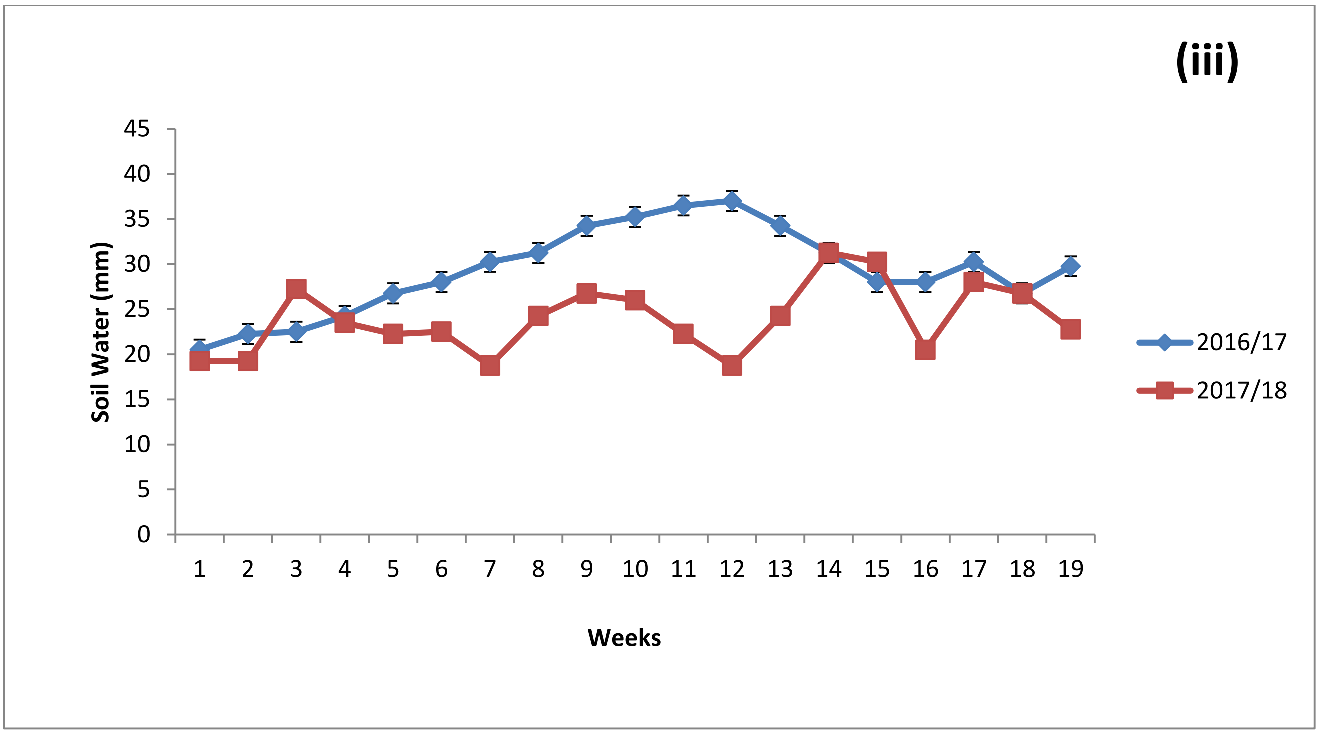
Table 4: Effect of mulch application rates on soil water content in growing 2016/17 and 2017/18.

Mulch Application Rate (t/ha)	Soil Water Content (mm)	
	2016/17	2017/18
0	30.08^{a}	20.05^{a}
2	29.53^{a}	23.15^{ab}
4	32.92^{a}	27.75^{b}
8	32.21^{a}	28.15^{bc}
p-value$_{(0.05)}$	ns	*
CV	10.17	19.90

Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ns = Not significant, CV=Coefficient variation.


(i)
Soil Water (mm)
0
5
10
15
20
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Weeks
2016/17
2017/18


(ii)
Soil Water (mm)
0
5
10
15
20
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Weeks
2016/17
2017/18



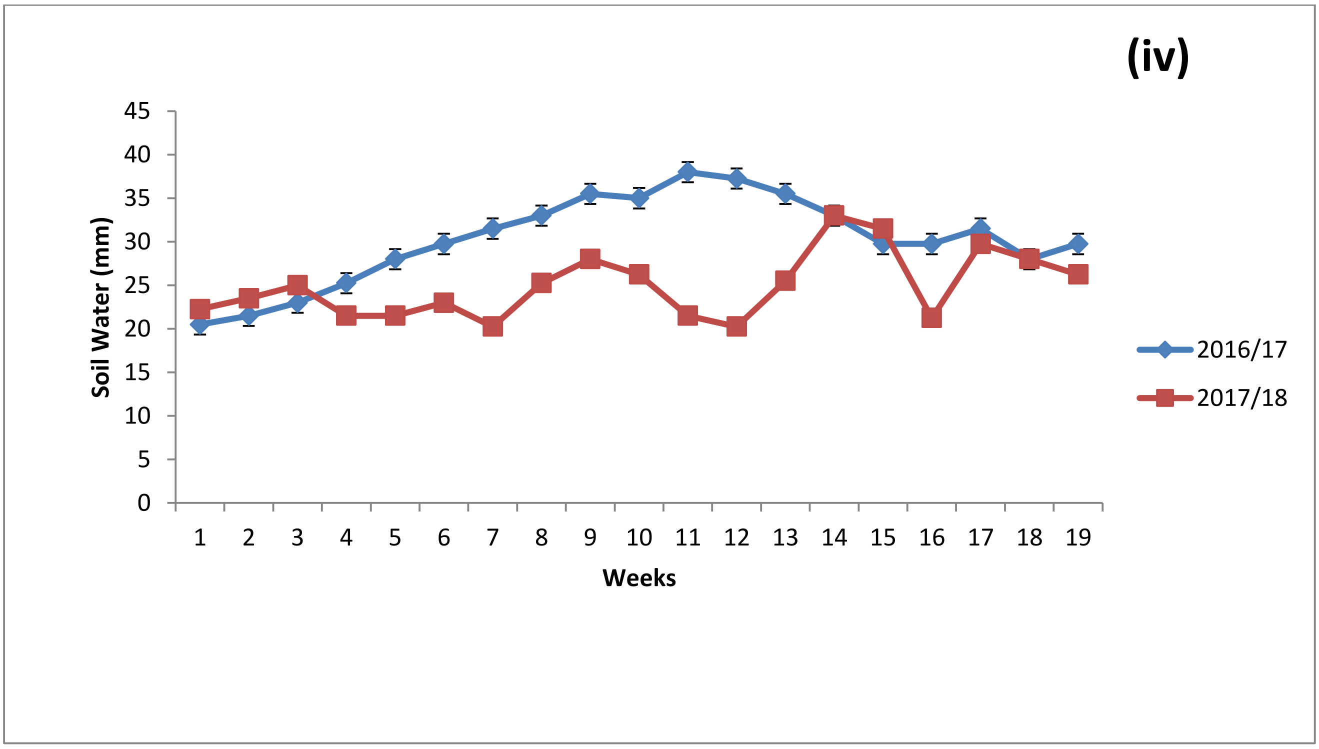
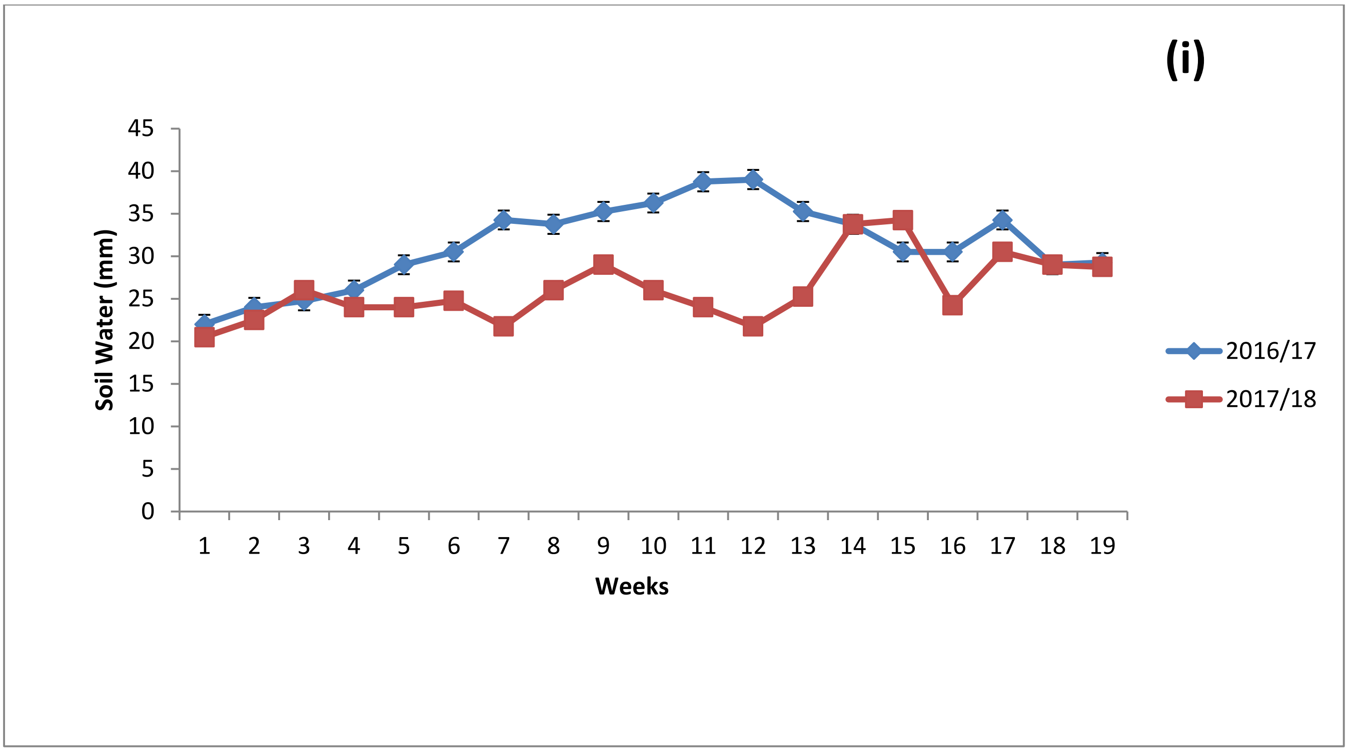
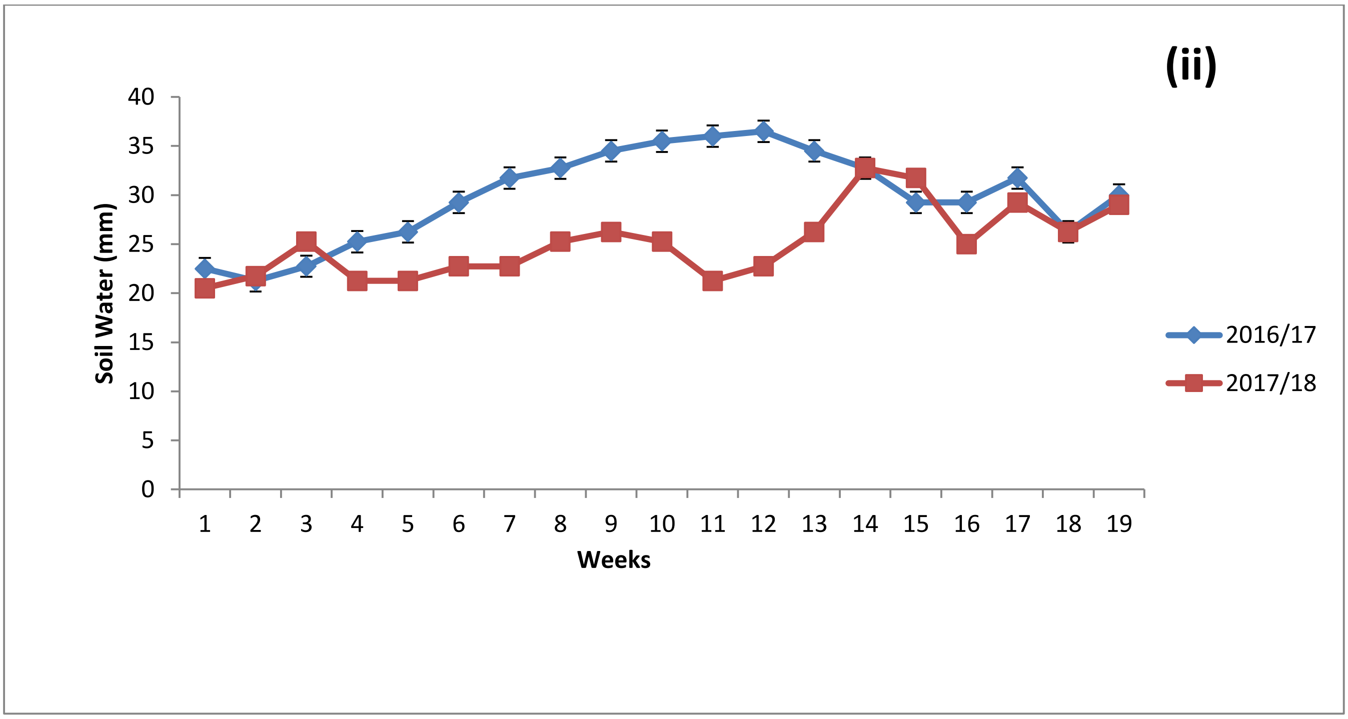
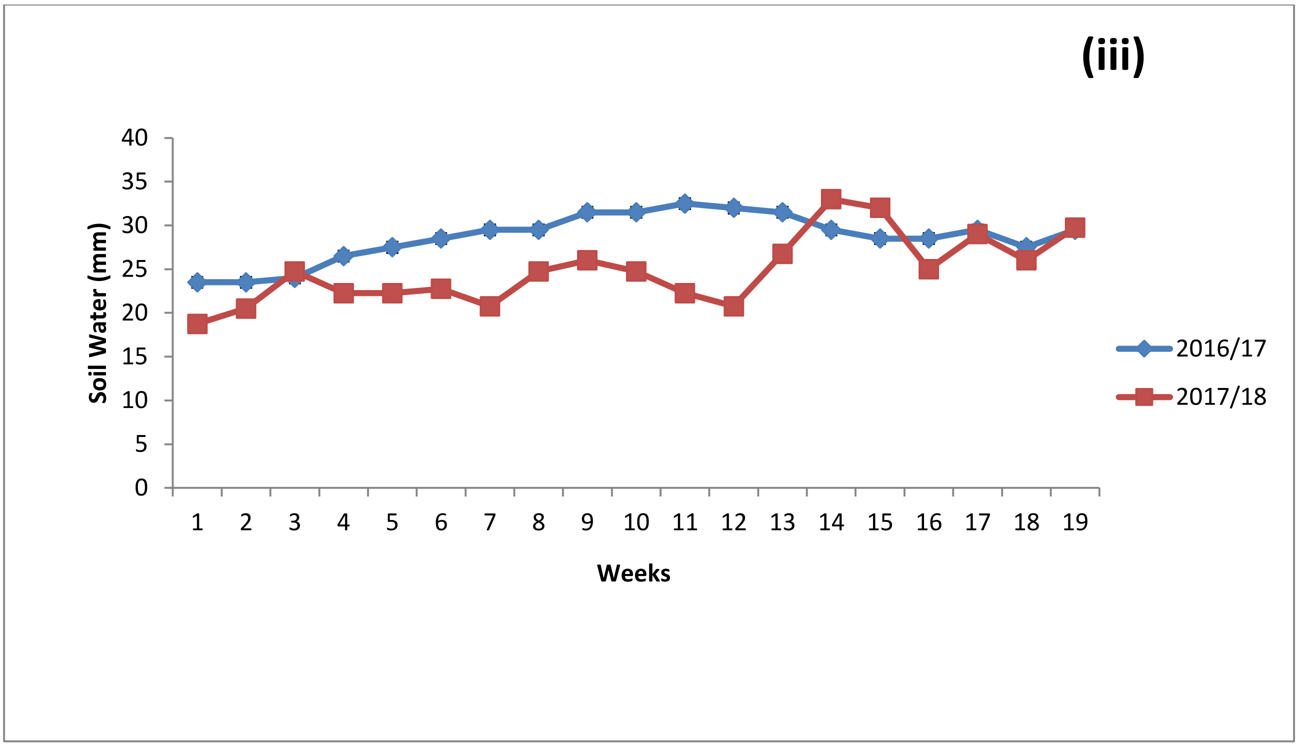


Figure 3(a): Soil Water Content (mm) at 0-30 cm depth at (i) 0 t/ha, (ii) 2 t/ha, (iii) 4 t/ha and (iv) 8 t/ha mulch application rates during the 2016/17 and 2017/18 cropping season. Bars indicate standard error.


(i)
Soil Water (mm)
0
5
10
15
20
25
30
35
40
45
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Weeks
2016/17
2017/18


(ii)
Soil Water (mm)
0
5
10
15
20
25
30
35
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Weeks
2016/17
2017/18



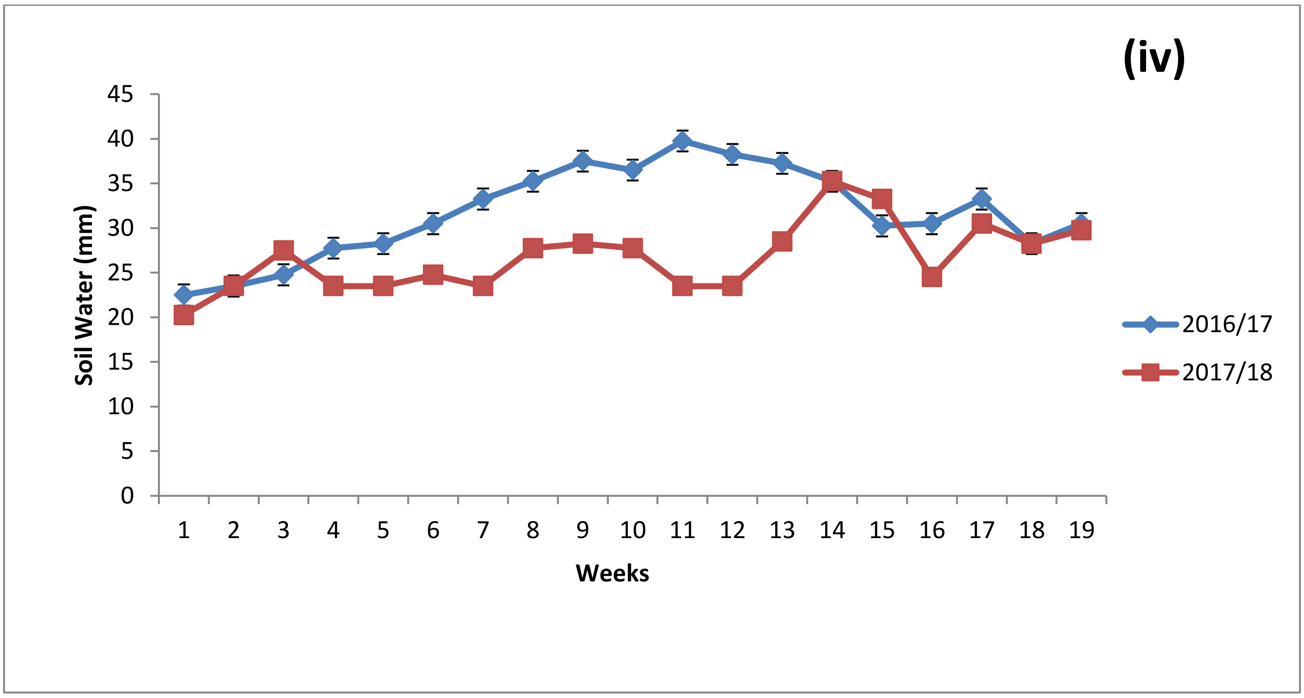
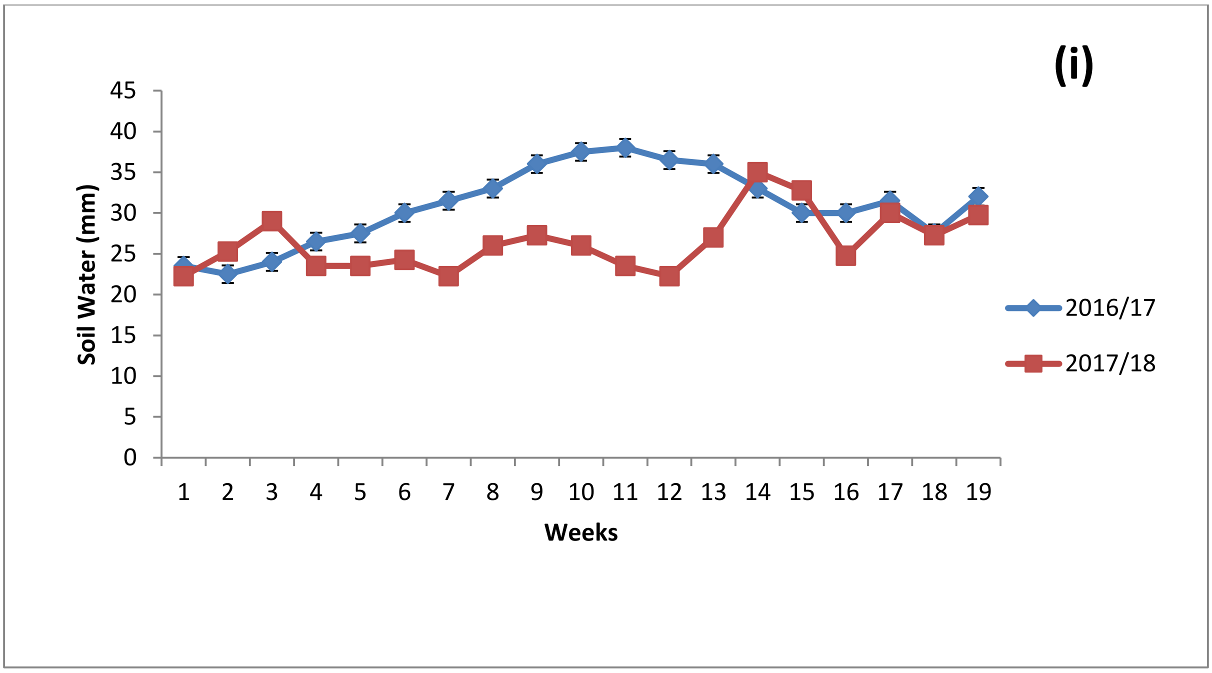
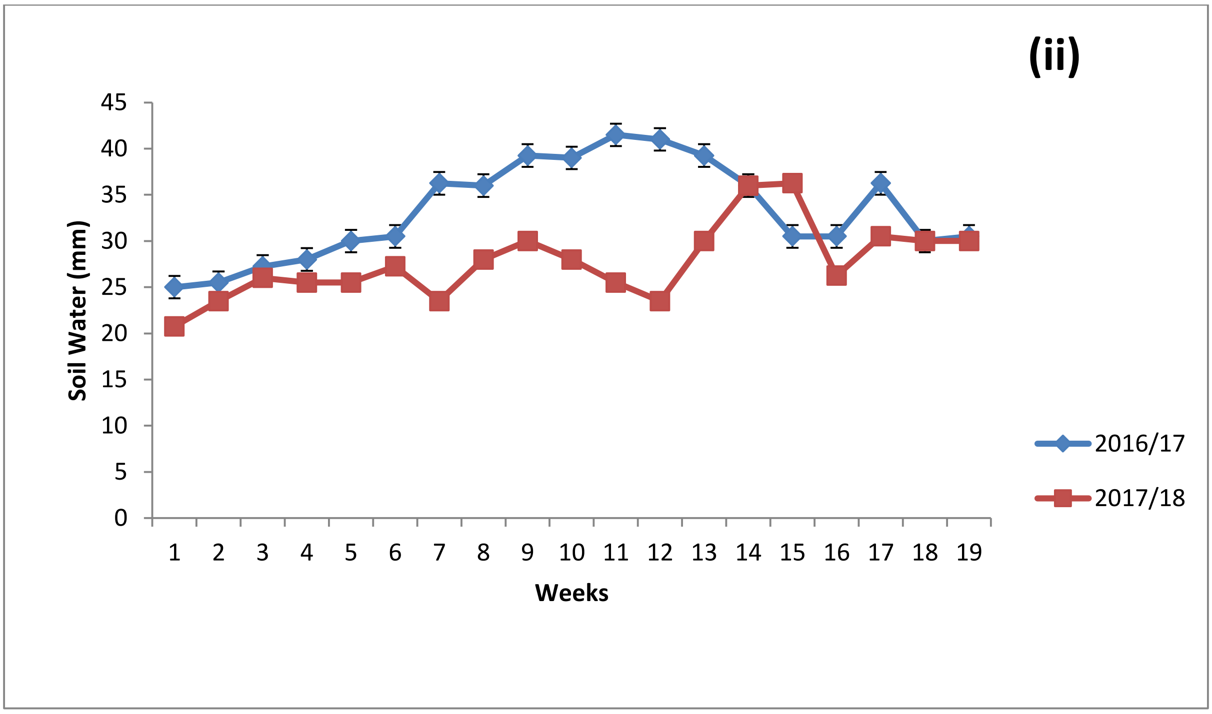
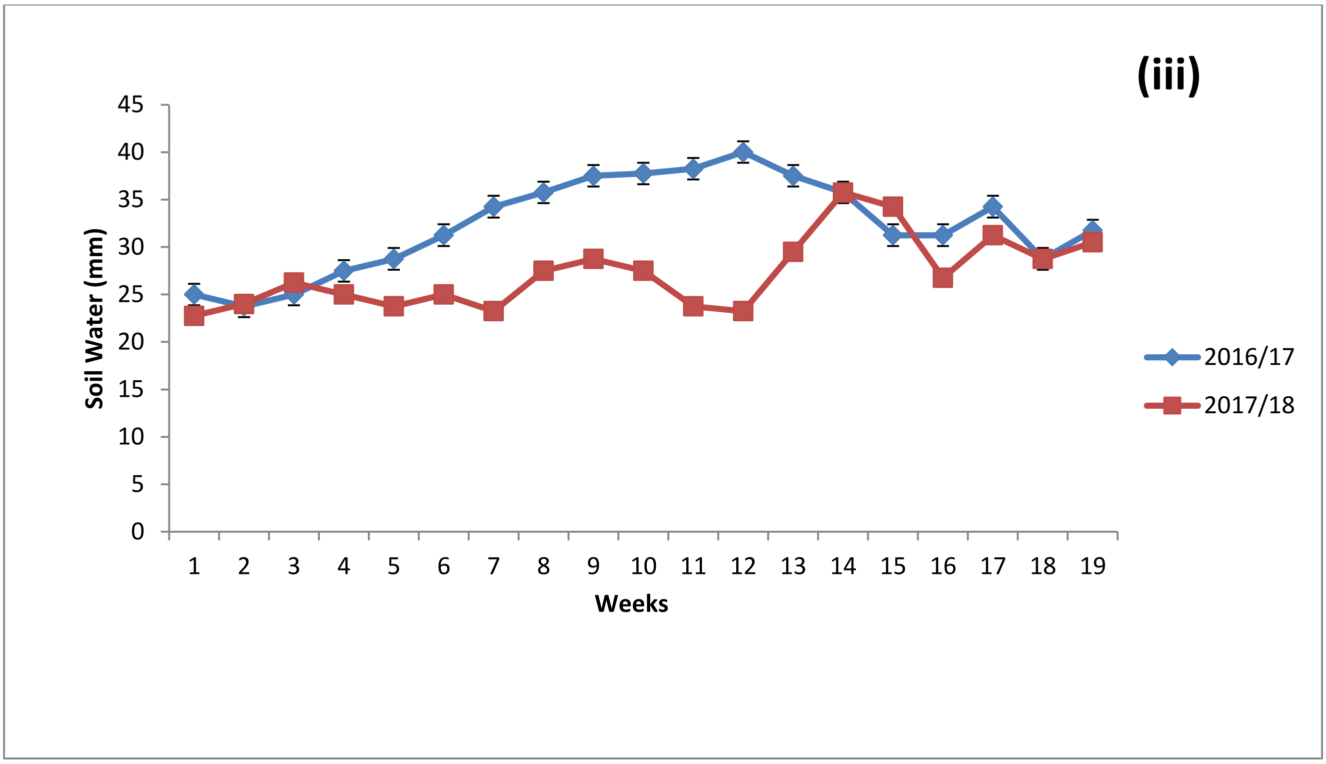


Figure 3(b): Soil Water Content (mm) at 30-60 cm depth (i) 0 t/ha, (ii) 2 t/ha, (iii) 4 t/ha and (iv) 8 t/ha mulch application rates during the 2016/17 and 2017/18 cropping season. Bars indicate standard error.


(i)
Soil Water (mm)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Weeks
2016/17
2017/18


(ii)
Soil Water (mm)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Weeks
2016/17
2017/18



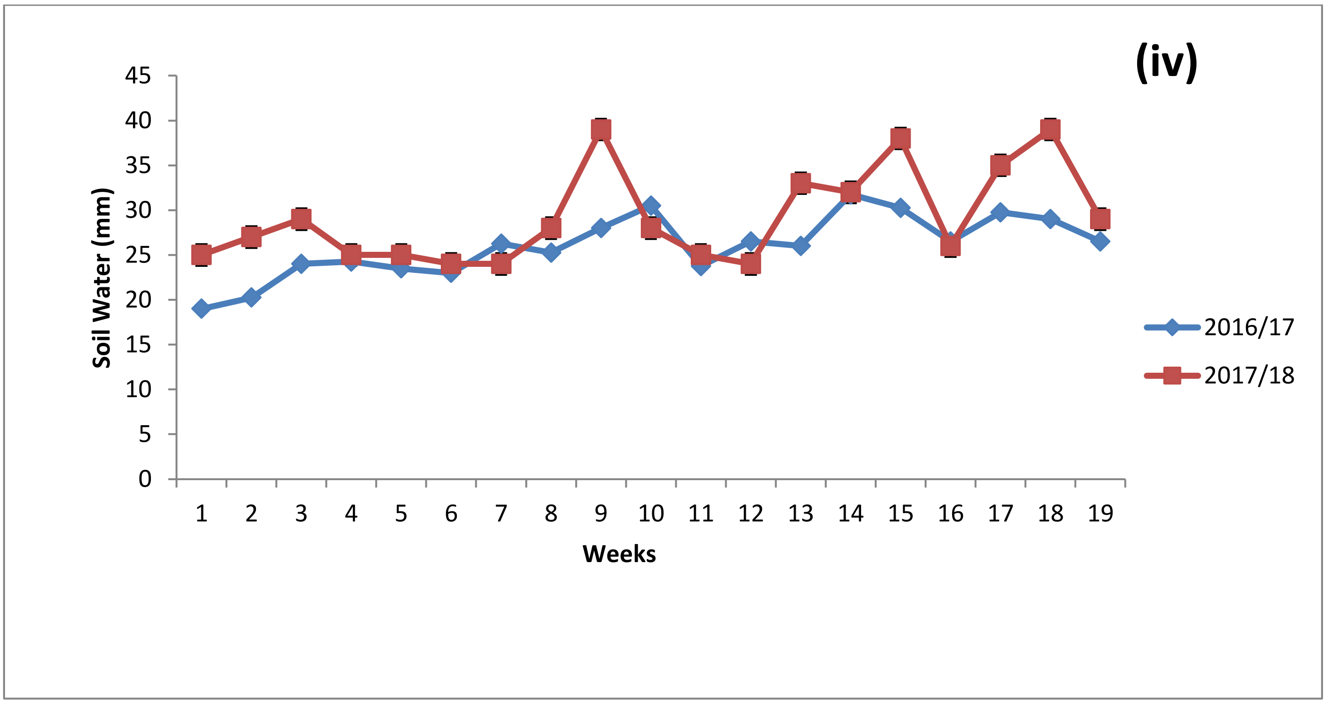


Figure 3(c): Soil Water Content (mm) at 60-90 cm depth (i) 0 t/ha, (ii) 2 t/ha, (iii) 4 t/ha and (iv) 8 t/ha mulch application rates during the 2016/17 and 2017/18 cropping season. Bars indicate standard error.

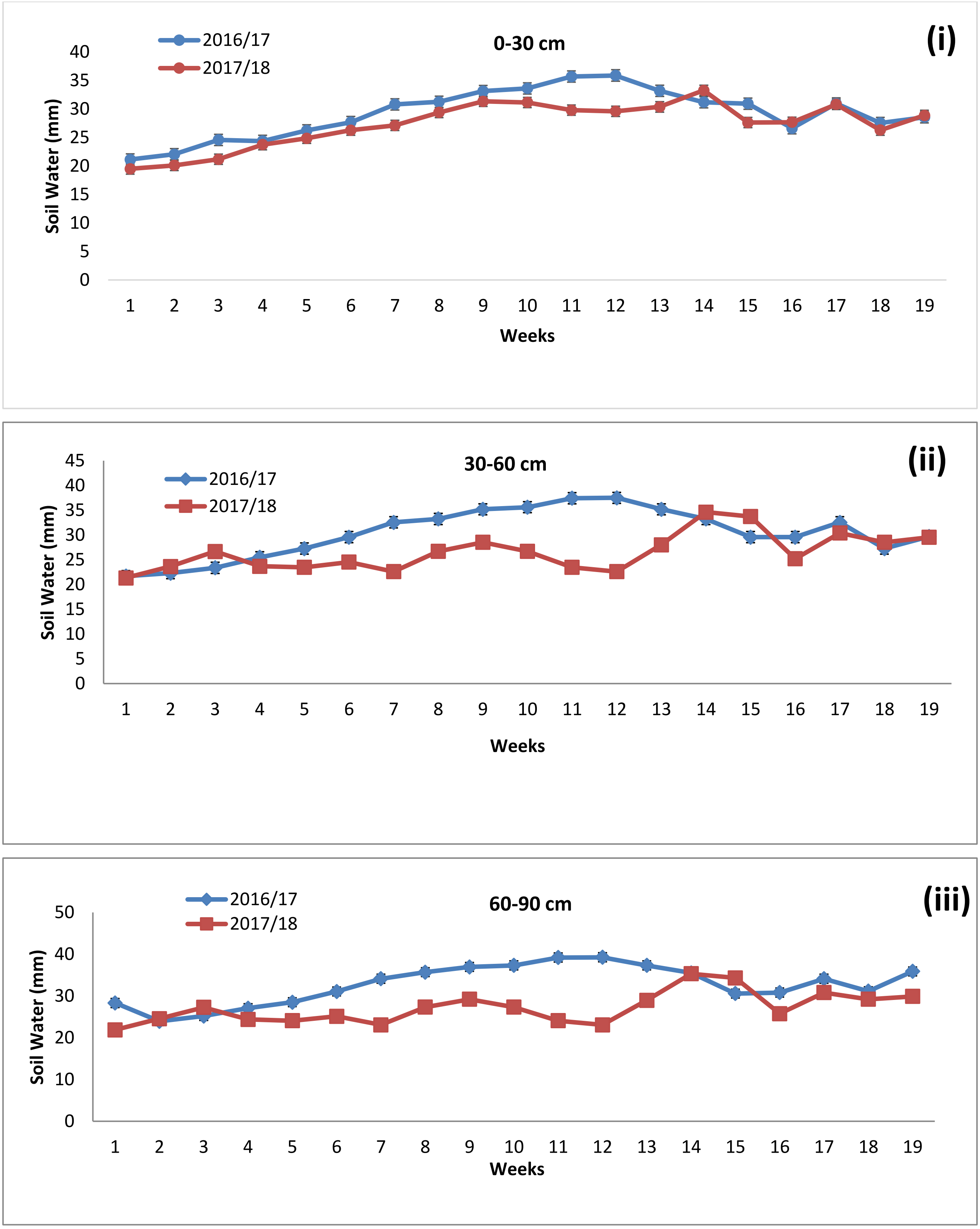


Figure 4: Average soil water content (mm) at different depths ((i) 0-30 cm, (ii) 30-60 cm and (iii) 60-90 cm) across all mulch application rates during 2016/17 and 2017/18 seasons. Bars indicate the standard error.

4.5 Effect of mulch application rates on water use efficiency.

The effect of treatments in terms of water use efficiency was significant (Table 5) in both seasons. Water use efficiency was highest at 4 t/ha mulch application rate with the 2016/17 season having the highest WUE at 24.4 kg/ha/mm and 2017/18 23.83 kg/ha/mm (Table 5). The mulch application rate that followed with the highest water use efficiency was the 8 t/ha mulch application rate then the 2 t/ha mulch application rate. The plots with no mulch, that is, the 0 t/ha mulch application rate had the lowest water use efficiency with the 2016/17 season having 13.23 kg/ha/mm and the second season 11.50 kg/ha/mm. The 2016/17 cropping season had higher water use efficiency than the 2017/18 season. This could be attributed to the 2016/17 cropping season having higher rainfall (Figure 2). It has been widely reported that mulch increases the WUE of crops (Peng *et al*., 2015; Qin *et al*., 2015; Zhang *et al*., 2003), which was the case in this study. Higher mulch application rates generally result in greater soil water storage at planting, which can enhance the germination and growth of cowpea in dryland farming systems but may not be enough to support yield formation and increase WUE (Deng *et al*., 2006). In order to improve crop yield in a semi-arid region, one needs to improve WUE (Shan and Chen., 1993; Zhao *et al*., 1995).

Table 5: Effect of mulch application rates on Water use efficiency

Mulch Application Rate (t/ha)	2016/17 (kg/ha/mm)	2017/18 (kg/ha/mm)
0	13.23^{a}	11.50^{a}
2	16.30^{ab}	15.43^{ab}
4	24.40^{c}	23.83^{c}
8	24.20^{bc}	22.96^{bc}
p-value$_{(0.05)}$	*	*
CV	37.19	39.16

Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ns = Not significant, CV=Coefficient variation.

4.6 Simulated and observed yield at different mulch application rates.

There was a good correlation of the observed and simulated yield values with an R^2 of 0.5 in 2016/17 and 2017/18. The internal model efficiency coefficient at 0.9 in 2016/17 and 0.9 in 2017/18 showed that the model's performance in predicting yield was good (Table 6). MdUAPE values of 9.3 and 7.8 were obtained for the 2016/17 and 2017/18 cropping seasons, respectively. Model simulations of cowpea grain yield under different mulch rates were very good for both seasons (RMSE=0.3). Approximately half of the observed variation can be explained by the model's inputs (R^2=0.5). The model's response of yield and biomass was similar to those observed by Cheerco-Nayamuth *et al*. (2000). Modelling together with short term field experiments can provide insights into long term system performance and variability than field trials alone.

In order to improve simulations, there is need to improve calibration of soil-water and water stress indices to improve the sensitivity of the model to crop water needs (Chimonyo *et al*., 2016). The greater reduction in grain yield in the 2017/18 cropping season might be attributed to exposure to higher temperatures during the grain filing period of the mulched crops. High temperatures during this period slowed down the rate of grain filling and accelerated senescence due to a decrease in photosynthetic activities per unit leaf area (Al-khatib and Paulsen, 1984; Zhao *et al*., 2007). E_i for both cropping seasons was 0.9 (Table 6).

Table 6: Comparison of simulated and observed yield at different mulch application rates.

	Yield					
	2016/17			2017/18		
Mulch Application Rate (t/ha)	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**
0	2165	2049	5.6	1398	1291	8.3
2	2563	2233	14.8	1997	1774	12.6
4	2779	3341	-16.8	2505	2965	-15.5
8	3777	3631	4.0	3753	3593	4.4
RMSE	0.3			0.3		
MdUAPE	9.3			7.8		
R^2	0.5			0.5		
E_i	0.9			0.9		

RMSE= root mean square error, R^2= coefficient of determination, E_i=modified coefficient of efficiency and MdUAPE= median unbiased absolute percentage error.

4.7 Simulated and observed total dry matter at flowering and harvest at different mulch application rates.

The APSIM model's ability to simulate observed cowpea yield and total biomass was tested under different levels of mulch application rates in both the 2016/17 and 2017/18 seasons. The trend of the growth of cowpea in response to mulch application rates was predicted reasonably by the model (Table 7). Similar findings were reported by Chimonyo *et al*. (2016). The model indicated the impact of mulch application rates in improving crop yield. This is well illustrated by the values between simulated and observed yields in both seasons, although the 4 t/ha mulch application rate in both seasons was predicted to produce less than the observed yield rate with a percentage error of -16.8% and -15.5%, respectively. Dry matter at harvest reported R^2 values of 0.5 for both seasons. This indicates that at least half of the observed variation can be explained by the inputs of the model. Both cropping seasons had an Ei value of 0.9 (Table 7), indicating that the model is better than the baseline comparison (usually the observed mean)

Overall, the model simulation of dry matter at flowering at different mulch rates was deemed satisfactory. Predictions were well suited; the model in general predicted the trend of dry matter at flowering, dry matter at harvest and yield under different mulch rates well (Table 7 and 8). The RMSE for dry matter at flowering in 2016/17 was 0.2 and 0.2 in the 2017/18 cropping season. The R^2 was 0.5 and E_1 in both seasons were 0.9 for both dry matter at harvest and flowering. MdUAPE was 4.5 in the 2016/17 cropping season and 5.3 in the2017/18 cropping season. Small deviations were noticed in dry matter at flowering, yield and total dry matter were observed in both seasons. This could be attributed to the weather data in the parameterization of the model. The weather station closest to the field site broke down and the nearest one was used for weather data, which means the weather data wasn’t exactly the same as that found by the experiment site, thus impacting the data generated by the model.

There was an underestimation of dry matter by the model at flowering as well as grain and total dry matter yield in both seasons, at 4 t/ha mulch application rate, with the simulated and observed data having a higher gap at harvest. The simulated trend was not like that observed in the field. This can be attributed to the weather data which was taken at the experimental site. However, the results showed a good performance in terms or r^2, E_1 and MdUAPE, of APSIM-Cowpea model during evaluation and validation under the given set of conditions. The difference between simulated and observed yield, dry matter at harvesting and flowering stage at 4 t/ha mulch application rate could be attributed to the overestimation of biomass and subsequent yield.

Table 7: Comparison of simulated and observed dry matter at harvest at different mulch application rates.

	Total dry matter (kg/ha)					
	2016/17			2017/18		
Mulch Application Rate (t/ha)	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**
0	8534	8411	1.5	7525	7793	-3.4
2	9205	9303	-1.1	8056	7629	5.6
4	9876	9976	-1.0	8587	8691	-1.2
8	11218	11144	0.7	9650	9706	-0.6
RMSE	0.3			0.4		
MdUAPE	0.07			0.02		
R^2	0.5			0.5		
E_i	0.9			0.9		

RMSE= root mean square error, R^2= coefficient of determination, E_i=modified coefficient of efficiency and MdUAPE= median unbiased absolute percentage error.

Table 8: Comparison of simulated and observed total dry matter at flowering at different mulch application rates.

	Dry matter at flowering (kg/ha)					
	2016/17			2017/18		
Mulch Application Rate (t/ha)	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**	**Simulated (kg/ha)**	**Observed (kg/ha)**	**Error (t/ha)**
0	245	242	1.4	206	178	15.3
2	268	261	2.8	241	257	-2.0
4	291	309	-5.8	287	344	-13.6
8	338	331	2.1	389	365	6.7
RMSE	0.2			0.2		
MdUAPE	4.5			5.3		
R^2	0.5			0.5		
E_i	0.9			0.9		

RMSE= root mean square error, R^2=coefficient of determination, E_i=modified coefficient of efficiency and MdUAPE= median unbiased absolute percentage error.

CHAPTER FIVE

5. Conclusions and Recommendations

5.1 Conclusion

The study concludes that application of mulch is very crucial in improving cowpea growth and yields. The results showed that mulch application rates affected cowpea yield, dry matter at harvest, water use efficiency as well as the soil water content, although, there were no significant differences for dry matter. The effects of the four mulch treatments on cowpea varied across seasons. Mulch was able to improve soil water availability. The 4 t/ha and 8 t/ha mulch application rates had higher grain yield and total dry matter in both seasons, whereas the control, 0 t/ha mulch yielded the least. Only yield was significantly different in both seasons. Dry matter had no significant difference at harvest and flowering stage. The higher crop yield can be partly attributed to increased soil water content due to mulch application.

Seasons influenced grain yield, total dry matter, water use efficiency and soil water content. The first season had above average rainfall while the second season was drier. The implication of this is that Vhembe is not a wet area but a semi-arid area where most farmers practice rain-fed agriculture. The yield difference between our findings and the annual world average (3 million tons) can be attributed to differences in rainfall amount, varieties used, soil fertility of the sites and the general agronomic practices where the cowpea was grown.

The APSIM-Cowpea model was able to simulate grain, total dry matter and soil water content with great accuracy. The model APSIM gave reliable simulations of yield, dry matter at flowering stage as well as dry matter at harvest under different mulch applications. The model can be used to guide smallholder farmers on mulching and its benefits to agricultural production in Vhembe district. Nevertheless, several model inputs will need to be determined with accuracy, such as minimum data sets for soil and weather data of the whole district.

5.2 Recommendations

Further studies are required to look at the simulation of APSIM-Cowpea production and the long-term scenarios as well as the models' simulation of mulch effects at different application rates. Improvements in the performance of the model APSIM can be enhanced if it is able to capture extreme events. Although costly and labour intensive, field trials should be set up considering seasonal rainfall conditions, using the best, second best and worst possible sets of management practices in order to determine the influence on cowpea yield. Further studies should focus on setting up APSIM for soil types, cultivars and crops grown in different parts of South Africa.

REFERENCES

Adams, J.E., Arkin, G.F., Ritchie, J.T. (1976). Influence of row spacing and straw mulch on 1st stage drying. Soil Science Society of America Journal, 40, 436-442.

Adeboye, B.O., Schultz, B., Adekalu, K.O. (2007). Soil water storage, yield, water productivity and transpiration efficiency of soybeans (*Glyxine max* L.*Merr*) as affected by soil surface management in Ile-Ife, Nigeria. International Soil and Water Conservation Research, 5, 141-150.

Al-Khatib, P.K., Paulsen, G.M. (1984). Mode of high temperature injury to wheat during grain development. Physiologia Plantarum, 61, 3.

Al-Rawahy, S.A., Al-Dhuhli, H.S., Prathapar S.A., Abdelrahman, H. (2011) Mulching material impact on yield. Soil moisture and salinity in saline-irrigated sorghum plots. International Journal of Agricultural Research, 6, 75-81.

Armstrong, J.S., Collopy, F. (1992). Error measure for generalizing about forecasting methods: empirical comparisons. International Journal of Forecasting, 8, 69-80.

Arora, V.K., Singh C.B., Sidhu A.S., Thind, S.S. (2011). Irrigation, tillage and mulching effects on soybean yield and water productivity in relation to soil texture. Agricultural Water Management, 98(4), 563-578.

ARC (Agricultural Research Counsel). (2018). The attributes of Cowpea. http://www.arc.agric.za/arcgci/Factt/ha20Sheetst/ha20Library/Cowpeat/ha20t/ha20Thet/ha20attributest/ha20oft/ha20cowpea.pdf [Accessed 14/02/2019].

Asiwe, J.A.N. (2007). Baseline survey on the production, constraints and utilization of cowpea in South Africa: Implications to cowpea improvement. Proceedings International Conference on indigenous vegetables and legumes: Prospects for fighting poverty, hunger and malnutrition. Organized by IPGRI, ICRISAT and ISHS, 12-15 December 2006 in Hyderabad, India. pp. 621-622.

Asiwe, J.A.N. (2009b). Needs assessment of cowpea production practices, constraints and utilization in South Africa. African Journal of Biotechnology. 8, 5383-5388.

Bailey, J. A., Nash, C., O'Connell, R. J., Skipp., R. A. (1990). Infection process and host specificity of a Co//etotrichum species causing anthracnose on cowpea, Vigna unguiculata. Mycological Research, 94(810-814).

Balwinder, S., Gaydon, D.S, Humphreys, E., Eberbach, P.L. (2011). The effects of mulch and irrigation management on wheat in Punjab, India-Evaluation of the APSIM model. Field Crops Research, 124, 1-13.

Balwinder, S., Humphreys, B., Eberbach, P.I., Katupitiya, A., Yadvinder, S., Kukai, S.S. (2011). Growth, yield and water productivity of zero till wheat as affected by rice straw mulch and irrigation schedule. Field Crop Research.121, 209-225.

Barron, J., Rockstrom, J., Gichuki, F., Hatibu, N. (2003). Dry spell analysis and maize yields for two semiarid locations in East Africa. Agricultural and Forest Meteorology, 177, 23-37.

Bean/Cowpea CRSP West Africa, Fy 96 Annual report October,1995-April, 1997 by Lowenberg-DeBoer, J. (also available at www.entm.purdue.edu/entomology research/cowpea/economict/ha20pages/impac.htm Bean/Cowpea CRSP West Africa, Fy 97 Annual report October>, 1995-April, 1997 by Lowenberg-DeBoer, J. (also available at www.entm.purdue.edu/entomology research/cowpea/economict/ha20pages/impac.htm Bean/Cowpea CRSP West Africa, Social Science Report April-Sept., 1998. Cowpea market structure studies, by Lowenberg-DeBoer, J. (available at www.entm.purdue.edu/entomology research/cowpea/economict/ha20pages/impac.html.

Blade, S.F., Singh, B.B. (1994). Providing options: Improving dry season cowpea production in Northern Nigeria. Agronomy Abstract, 75.

Blake, G. R., Hartge, K.H. (1986). Bulk Density. In A. Klute (ed.) Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods (2nd edition.), (pp.54-58). Madison Wisconsin: American Society of Agronomy.

Brady, N.C., Weil, R.R. (2008). The nature and properties of soils. Pearson Prentice Hall, Columbus.

Bray. R.H., Kurtz, T. (1942). Determination of total organic and available forms of phosphorus in soils. Soil Science, 59, 39-45.

Bouyoucos, C.J. (1962). Hydrometer method improved for making particle size analysis of soils. Agronomy Journal, 54, 464-465.Bremmer, J.M. and Mulvaney, D.C.S. (1982). Nitrogen-Total: In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Methods of soil analysis, (pp595-624). Madison Wisconsin: American Society of Agronomy and Soil Science Society of America.

Bunna, S., Sinath, P., Makara O., Mitchell, J., Fukai, S. (2011). Effects of straw mulch on mungbean yield in rice fields with strongly compacted soils. Field Crops Research, 124, 295-301.

Chakraborty, D., Nagarajan, S., Aggarwal, P., Gupta, V.K., Tomar, R.K., Garg, R.N., Sahoo, R.N., Sarkar, A., Chopra, U.K., Sundara Sarma, K.S., Kalra, N. (2008). Effect of mulching on soil and pla nt water status and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. Agricultural Water Management, 95(12), 1323-1334.

Chalker-Scott, L. (2007). Impact of mulches on landscape plants and the environment - a review. Journal of Environmental Horticulture, 25(4), 239-249.

Cheerco-Nayamuth, F.C., Robertson, M.J., Wegenar, M.K., Nayamuth, A.R.H. (2000). Using simulation model to assess potential and attainable sugarcane yield in Mauritius. Field Crops Research, 66, 225-243.

Chen, S.Y., Zhang, X.Y., Pei, D., Sun, H.Y., Chen, S.I. (2007). Effects of straw mulching on soil temperature, evaporation and yield of winter wheat; field experiments on the North China Plain. Annals of Applied Biology. 150, 261-268.

Chen, Y., Liu, T., Tian, X., Wang, X., Li, M., Wang, S., Wang, Z. (2015). Effects of plastic film combined with straw mulch on grain yield and water use efficiency of winter wheat in loess plateau. Field Crops Research. 172, 53–58.

Chen, Y., Chai, S., Tian, H., Chai, Y., Li, Y., Chang, L., Cheng, H. (2019). Straw strips mulch on furrows improves water use efficiency and yield of potato in a rain-fed semi-arid area. Agricultural Water Management, 211, 142-151.

Chimonyo, V.G.P., Modi, A.T., Mubidudu, T. (2016). Simulating yield and water use of sorghum-cowpea intercropping using APSIM. Agricultural Water Management, 177, 317-328.

Condon, A.G., Richards, R.A., Rebetzke, G.J., Farquhar, G.D. (2002). Improving intrinsic water-use efficiency and crop yield. Crop Science, 42, 122-131.

Department of Agriculture, Forestry and Fisheries (DAFF). (2011). Production guidelines for Cowpea. Compiled by Directorate Plant Production in collaboration with the ARC. http://www.arc.agric.za/arc-gci/Factt/ha20Sheetst/ha20Library/Cowpeat/ha20-t/ha20Productiont/ha20guidelinest/ha20fort/ha20cowpea.pdf [Accessed 03/05/2016].

Deng, X.P., Shan, L., Zhang, H.P., Turner, N.C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. Agricultural Water Management, 80, 23-40.

Díaz, F., Jiménez, C.C., Tejedor, M. (2005). Influence of the thickness and grain size of tephra mulch on soil water evaporation. Agricultural Water Management, 74, 47–55.

Dimes, J., Achien, J., Mesfin, T., Abeya, T., Makoko, B., Nhantumbo, N., Rodriguez, D. (2011). Evaluation of APSIM to simulate maize-bean cropping systems in eastern and southern Africa: an alternative approach. 5th World Congress on Conservation Agriculture and Farming Systems Design Australian Centre for International Agricultural Research, 1-4.

Dong, Q.G., Yang, Y., Yu, K., Feng, H. (2018). Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogrn fractions, crop yield and water use efficiency in Loess Plateau, China. Agricultural Water Management, 201, 133-143.

Doring, T.F., Brandt, M., Heß., Finckh, M.R., Saucke. H. (2005). Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crop Research, 94, 238-249.

Ehlers, J.D., Halle, A.E. (1997). Cowpea (*Vigna unguiculata* L. *Walp*.). Field Crops Research, 53, 187-204.

Emechebe, A.M., Fiorini, D. A. (1997). Shoot and pod diseases of cowpea induced by fungi and bacteria, 178-192. In Advances in Cowpea Research (Eds. Singh, B.B., Mohaj Raj, D. R., Dashiell, K.E., Jackai, L. E. N.) Sayce Publishing, Devon, UK.

Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil Tillage and Research, 67, 115-133.

FAOSTAT, (2015). FAO Statistics Division 20015.

Fan, J.L., Wu, L.F., Zhang, F.C., Xiang, Y.Z. (2017). Climate change effects on reference crop evapotranspiration across different climatic zones of China during 1956-2015. Journal of Hydrology, 542, 923-937.

Farooqi Z.U., Sabir M., Zeeshan N., Naveed, K., Hussain, M.M. (2018). Enhancing carbon sequestration using organic amendments and agricultural practices, carbon capture, utilization and sequestration. https://www.intechopen.com/books/carbon-capture-utilization-and-sequestration/enhancing-carbon-sequestration-using-organic-amendments-and-agricultural-practices. IntechOpen. https://doi.org/10.5772/intechopen.79336. {Accessed 27/08/2020}

Food and Agricultural Organization Statistical (FAOSTAT). (2013). http://apps.fao.org/faostat/collections. [Accessed 14/11/2018]

Findeling, A., Ruv, S., Scopel, E. (2003). Modelling the effects of a partial residue mulch on runoff using a physically based approach. Journal of Hydrology, 275, 49-66.Fery, R.L. (1990). Cowpea production in the United States. Horticultural Science, 16, 473-474.

Goitom T., Alemtsahay T., Berhanu A. (2017). Effect of organic mulching on soil moisture, yield and yield contributing components of Sesame. https://doi.org/10.1155/2017/4767509 [Accessed17/11/2017]

Gu, X.B., Li, Y.N., Du, Y.D. (2017). Biodegradable film mulching improves soil temperature, moisture and seed yield of winter oilseed rape (*Brassica napus* L.). Soil and Tillage Research. 171, 42-50.

Feng, Y., Hao, W., Gao, L., Li, H., Gong, D., Cui, N. (2019). Comparison of maize water consumption at different scales between mulched and non-mulched croplands. Agricultural Water Management, 216, 315-324.

Hall, A.E. (2004). Breeding for adaption to drought and heat in cowpea. European Journal of Agronomy, 21, 447-454.

Hall, A.E., Mutters, R.G., Hubick, K.T., Farquhar, G.D. (1990). Genotypic difference in carbon isotope discrimination by cowpea under wet and dry field conditions. Crops Science, 30, 300-305.

Hall, A.E. (2012). Phenotype cowpeas for adaptation to drought. Frontiers in Physiology, 3,155.

Haq, I. (2000). Effect of mulching on root zone moisture content and yield of yield of different sunflower varieties under rain-fed conditions. NAUP, Peshawar (Pakistan), 127.

Hatibu, N., Mutabazi, K., Senkondo, E.M., Msangi, A.S.K. (2006). Economics of rainwater harvesting for crop enterprises in semiarid areas of East Africa. Agricultural Water Management, 80, 74-86.

Hattlendorf, M.J., Redelfs, M.S., Amos, B., Stone, L.R., Gwin, R.E. (1988). Comparative water use characteristics of six row crops. Agronomy Journal, 80, 80-85.

Harris, H.F., Thies J.A., Fery, R.L. (2006). Evaluation of Cowpea Genotypes for Use as a Cover Crop. Horticultural Science, 41 (5), 1145-1148.

Holzworth, D.P., Janssen, S., Snow, V., Donatelli, M., Athanasiadis, I.N., Hoogenboom, G., Thorburn, P., White, J.W. (2014). Agricultural systems modeling and software: current status and future prospects. Environmental Modelling Software, 62, 411-419.

Hou, X.Y., Wang, F.X., Han, J.J., Kang, S.Z. (2010). Duration of plastic mulch for potato growth under drip irrigation in an arid region of Northwest China. Agriculture and Forest Meteorology, 150, 155-121.

Hou, F.Y., Zhang, L.M., Xie, B.T., Dong, S.X., Zhnag, H.Y., Li, A.X., Wang. (2015). Effect of plastic mulching on photosynthetic capacity, endogenous hormones and root yield of summer-sown sweet potato (*Ipompoea batata* (L). Lam.) in Northern China. Acta Physiologiae Plantarum, 32, 1-10.

Howell, T.A., Yazar, A., Schneıder, A.D., Dusek, D.A., Copeland, K.S. (1995). Yield and water use efficiency of corn in response to Low Energy Precise Application (LEPA) irrigation. Transaction of the American Society of Agricultural Engineers, 38(6), 1737–1747.

Huang, Y., Chen, L., Fu, B., Huang, Z., Gong, J. (2005). The wheat yields and water use efficiency in the Loess Plateau: straw mulch and irrigation effects. Agricultural Water Management, 72(3), 209-222.

IITA Research, (2001). (Available at www.iita.org/research/summaries/sumproj_8.htm) [Accessed 11/09/2016].

Imrie, B. (2000). Cowpea. (Available at www.rirdc.go.au/pub/hankbook/cowpea. pdf) [Accessed 11/09/2016].

Jaetzold, J.R., Schmidt, H., Hornetz, B., Shisanya, C. (2006). Farm management handbook of Kenya. Natural conditions and farm information, vol. II: Nairobi: Ministry of Agriculture, Kenya.

Jalota, S.K. & Prihar, S.S. (1998). Reducing soil water evaporation with tillage and straw mulching. 2121 South Iowa State University Press, State Avenue, Ames, Iowa 50014. https://www.daff.gov.za/Daffweb3/Portals/0/Brochurest/ha20andt/ha20Productiont/ha20guidelines/Postert/ha20Mulchin.pdf and http://ezinearticles.com/?Different-Types-of-Mulch---Agronomy Research Advantages-and-Disadvantages&id=1235265 [Accessed 12/12/2018]

Jayathilake, C., Visvanathan, R., Deen, A., Bangamuwage, R., Jayawardana, B.C., Nammi, S., Liyanage, R. (2018). Cowpea: an overview on its nutritional facts and health benefits. Journal of the Science of Food and Agriculture,98(13), 4793-4086.

Ji, S., Unger, P.W. (2001). Soil water accumulation under different precipitation, potential evaporation and straw mulch conditions. Soil Science Society of America Journal, 65, 442-448.

Jodaugiene, D., Pupalien, R., Urboniene, M., Prankiestis, V., Pranckietiens, I. (2006). The impact of different types of organic mulches on weed emergence. Agronomy Research, 4, 197-201.

Kader M.A., Senge, M., Mojid, M.A., Nakamura, K. (2017). Mulching type-induced soil moisture and temperature regimes and water use efficiency of soybean under rain-fed condition in central Japan. International Soil and Water Conservation Research, (5) 4, 302-308.

Kader, M.A., Senge, M., Mojid, M.A., Nakamura, K. (2017b). Mulching type induced soil moisture and temperature regimes and waer use efficiency of soybean under rain-fed condition in central Japan. International Journal of Soil Water Conservation Research, 5, 302-308

Kader, M.A., Singha, A., Begum, M.A., Jewel, A., Khan, F.H., Khan, N.I. (2019). Mulching as water-saving technique in dry land agriculture. Bulletin of the National Research Centre, 43,1–6.

Kar, G., Singh, B. (2004). Soil water retention-transmission studies and enhancing water use efficiency of winter crops through soil surface modifications. Indian Journal of Soil Conversation, 32(1), 18-23.

Kasirajan, S., Ngouajio, M. (2012). Polythylene and biodegradable mulches for agricultural applications:a review. Agronomy for Sustainable Development, 32, 501-529.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinkie, H., Hochman, Z., Mclean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J. (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy, 18(3-4), 267-288

Knorzer, H., Lawes, R. (2011). Evaluation and performance of the APSIM model for German winter wheat, maize and fieldpea varieties in monocropping and intercropping. Agricultural Science and Technology Journal, 1, 698-717.

Kobayashi, K., Salam, M.U. (2000). Comparing simulated and measured values using mean squared deviation and its components. Agronomy Journal, 92, 345-352.

Kormawa, P. M., Chianu, J. N. and Manyong, V. M. (2002). Cowpea demand and supply patterns in West Africa: the case of Nigeria. IN FATOKUN, C. A., TARAWALI, S. A., SINGH, B. B., KORMAWA, P. M., TAMO, M. (1st edition) Challenges and Opportunities for enhancing sustainable Cowpea production. International Institute of Tropical Agriculture.

http://www.farmersweekly.co.za/article.aspx?id=5311&h=Cowpea-replace-maize-on-a-Free-State-farm [Accessed 08/07/2016].

Kouwenhoeven, J.K., Perdok, U.D., Boer, J., Oomen, G.J.M. (2002). Soil management by shallow mouldboard ploughing in the Netherlands. Soil and Tillage Research, 65, 125-139.

Kumar, D., Singh, R., Gadekar, H., Patnaik, U.S. (2003). Effect of different mulches on moisture conservation and productivity of rain-fed turmeric. Indian Journal of Soil Conservation, 32(1), 41-44.

Kumar, S., Dey., P. (2011). Effects of differnet mulches and irrigation methods on root growth, nutrient uptake, water-use efficiency and yield of strawberry. Scientia Horticulture, 127, 318-324.

Langyintuo, A. S., Lowenberg-DeboerJ., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Kushwaha, S., Musa, S., Ntoukam, G. (2003). Cowpea supply and demand in West and Central Africa. Field Crops Research, 82**,** 215-231.

Latunde-Dada, A. 0., O'Connell, R. J., Nash, C., Pring. R. J., Lucas, J. A., Bailey, J. A. (1996). Infection process and identity of the hemibiotic anthracnose fungus (Co//etotrichum destructivum) from cowpea (*Vigna unguiculata*). Mycological Research, 100, 1133-1141.

Li, F., Wang, J., Xu, J. (2005). Plastic film mulch effect on spring wheat in a semi-arid region. Journal of Sustainable Agriculture, 25(4), 5-17.

Li, S.X., Wang, Z.H., Li, S.Q. Gao, Y.J., Tian, X.H. (2013) Effects of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation on dryland areas of China. Agriculture Water Management, 116, 39-49.

Li, Y., Gu, X., Du, Y. (2016). Continuous ridges with film mulching improve soil water content, root growth, seed yield and water use efficiency of winter oilseed rape. Industrial Crops and Products, 85, 139-148

Lin, Z.H.U., Jiam-liang, L.I.U., Ling-duo, B.U., Xin-ping, C., Shi-qing, L.I. (2015). Soil Mulching can mitigate soil water deficiency impacts on rainfed maize production in semiarid environments. Integrative Agriculture, 14(11), 58-66.

Lipic, J., Kus, J., Slowinska-Jurkiewicz, A., Nosalewicz, A. (2005). Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage Research, 89, 210-220.

Lui, E.K., He, W.Q., Yan, C.R. (2014). White revolution to white pollution – agriculture plastic film mulch in China. Environmental Research Letters. 9,091001.

Lui, Y., Li, S.Q., Chen, F., Yang, S.J, Chen, X.P. (2010). Soil water dynamics and water use efficiency in spring maize (*Zea mays* L.) field subjected to different water management practices on the loess Plateau, China. Agricultural Water Management, 97, 769-775.

Ma, D., Chen, L., Qu, H., Wang, Y., Misselbrooke, T., Jiang, R. (2018). Impacts of plastic film mulching on crop yields soil water, nitrate and organic carbon in Northwestern China: a meta-analysis. Agricultural Water Management, 179, 166-173.

MacCarthy D.S., Sommer R., Vlek P.L.G. (2009). Modeling the impacts of contrasting nutrient and residue management practices on grain yield of sorghum (*Sorghum bicolor* (L.) *Moench*) in semi-arid region of Ghana using APSIM. Field Crops Research, 113, 105-115.

Mahajan, G., Sharda, R., Kumar, A., Singh, K.G. (2007). Effect of plastic mulch on economizing irrigation water and weed control in baby corn sown by different methods. African Journal of Agricultural Research, 2(1),19-26.

Martin, B., Ruiz-Torres, N.A. (1992). Effects of water-deficit stress on photosynthesis, its components and component limitation and on water use efficiency in wheat (*Triticum aestivum* L.). Plant Physiology, 100, 733-739.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., Freebairn, D.M. (1996). APSIM: A novel software system for model development, model testing and simulation in agricultural systems research. Agricultural Systems, 50, 255-271.

Mo, F., Li, F.J., Zhang, C.R., Li, S.K., Xiong, Y.C. (2018). Alternating small and large ridges with full film mulching increase linseed (*Linum usitatissimum* L.) productivity and economic benefit in a rainfed semiarid environment. Field Crops Research, 219, 120-130.S

Miriti, J.M., Kironchi, G., Esilaba, A.O., Heng, L.K., Gachene, C.K.K., Mwangi, D.M. (2012). Yield and water use efficiencies of maize and cowpea as affected by tillage and cropping systems in semi-arid Easter Kenya. Agricultural Water Management, 115, 148-155.

Moroke, T.S., Schwartz, R.C., Brown, K.W., Juo, A.S.R. (2011). Water efficiency of dryland cowpea, sorghum and sunflower under reduced tillage. Soil and Tillage Research, 112, 76-84.

Mukherjee, D., Mitra, S., Das, A.C. (1991). Effect of organic matter cakes on changes in carbon, nitrogen, and microbial population in soil. Journal of the Indian Society of Soil Science, 39, 121-126.

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N., Foley, J.A. (2012). Closing yield gaps through nutrient and water management. Nature, 490, 254.

Mulumba, L.N. and Lal, R. (2008). Mulching effects on selected soil physical properties. Soil and Tillage Research, 98 (1), 106-111.

Mupangwa, W., Twomlow, S., Walker, S. (2007). Minimum tillage and mulching effect on cowpea (*Vigna unuiculata L. Walp*.) yield and soil water. Bloemfontein: University of Free State.

Mupangwa W., Twomlow, S., Walker, S. (2012). Reduced tillage, mulching and rotational effects on maize (*Zea mays* L.) cowpea (*Vigna unguiculata (Walp)* L.) and sorghum (*Sorghum bicolor* L.) yields under semi-arid conditions. Field Crops Research, 132, 139-148.

Mzezewa, J., Misi, T., Van Rensburg, L.D. (2010). Characterisation of rainfall at a semi-arid ecotope in the Limpopo Province (South Africa) and its implications for sustainable crop production. Water South Africa, 36 (1), 19-26.

Nash, J.E., Sutcliffe, J.V. (1970). River flow forecasting through conceptual models part 1 – discussion of principles. Hydrological Journal, 10 (3), 282-290.

Nelson, D.W. and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (1st edition). Methods of Soil Analysis: Chemical and Microbiological Properties (2nd edition). Agronomy Society of America, 2, 553-579.

Ncube, B., Twomlow, S.J., van Wijk, M.T., Dimes, J.P., Giller, K.E. (2007). Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in southwestern Zimbabwe. Plant Soil, 299, 1-15.

Ncube, B., Dimes, J.P., van Wijk, M.T., Twomlow, S.J., Giller, K.E. (2009). Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south-western Zimbabwe. Plant Soil, 299, 1-15.

Ncube, B., Dimes, J.P., van Wijk, M.T., Twomlow, S.J., Giller, K.E. (2009). Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south-western Zimbabwe. Unravelling the effects of water and nitrogen using simulation modelling. Field Crops Research, 110, 173-148.

NDA (National Department of Agriculture). (2009). Production guidelines for cowpeas. http://www.nda.agic.za?docs?Infopark-cowpea booklet.pdf [Accessed 17/11/2017].

Ngalamu, T., Odra, J., Tongun, N. (2014). Cowpea production handbook. University of Juba. https://www.researchgate.net/publication/284900187 [Accessed 09/07/2016].

Nyakudya, I.W., Stroosnijder, L. (2011). Water management options based on rainfall analysis for rainfed maize (*Zea mays* L.) production in Rushinga district, Zimbabwe. Agricultural Water Management, 98, 1649-1659.

Nalayini, P. (2007). Poly-mulching a case study to increase cotton productivity. Senior scientist, Central Institute for Cotton Research, Regional Station, Coimbatore

Obatolu, V.A. (2003). Growth pattern of infants fed with a mixture of extruded malted maize and cowpea. Nutrition, 19**,** 174-178.

Ofuso-Amin, J., Limbani, N.V. (2007). Effect of intercropping on the growth and yield of cucumber and okra. International Journal of Agriculture and Biology, 9(4),594−597.

Ogola, J.B.O., Thangwana, N., Mathews, C. (2009). Water use of chickpea: response to genotype and planting density. African Crop Conference Proceeding, 9, 217-219.

Onesirosan, P. T., Barker, L. N. (1971). Stem anthracnose of cowpea in Nigeria. Plant Disease Reporter, 55, 820-822.

Ossom, E.M., Pace, P.F., Rhykerd, R.L., Rhykerd, C.L. (2001). Effect of mulch on weed infestation, soil temperature, nutrient concentration and tuber yield in *(Ipomoea batatus* (L.)) Lam. in Papua New Guinea. Tropical Agriculture (Trinidad), 78, 144-151.

Pandey, R.K., Herrera, W.A.T., Pendleton, J.W. (1984). Drought response of grain legumes under irrigation gradient: yield and yield components. Agronomy Journal, 76, 549-553.

Parry, M.A.J., Flexas, J., Medrano, H. (2005). Prospects for crop production under drought: research priorities and future directions. Annals of Applied Biology, 147, 211-226.

Peech, M. (1965). Lime requirements. In: Methods of soil analysis, Black, C.A. (ed). American Society of Agronomy. (pp927-932). Madison, Wisconsin, USA.

Peng, Z., Ting, W., Haixia, W., Min, W., Xiangping, M., Siwei, M., Rui, Z., Zhikuan, J., Qingfang, H. (2015). Effects of straw mulch on soil water and winter wheat production in dryland farming. Scientific Reports. 5(10725).

Phillips, R.D., Mcwatters, K.H., Chinnan, M.S., Hung, Y. C., Beuchat, L. R., Sefa-Dedeh, S., Sakyi-Dawson, E., Ngoddy, P., Nnanyelugo, D. and Enwere, J. (2003). Utilization of cowpea for human food. Field Crops Research, 82**,** 193-213.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., Strong, W.M. (1998). APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. Agriculture System, 56, 1-28.

Probert, M.E., Keating, B.A., Thompson, J.P., Parton, W.J. (1995). Modelling water nitrogen and crop yield for a long-term fallow management experiment. Australian Journal of Experimental Agricultural, 35, 941-950.

Qin, W., Hu, C., Oenema, O. (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: a meta-analysis. Scientific Reports, 5(16210).

Rahman, M.A., Chikushi, J., Saifizzaman, M., Lauren, J.G. (2005). Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Research, 91(1), 71-81.

Raju, L.B. (2013). Effect of mulching on crop production under rainfed condition – a review. Agricultural Reviews, 34(3), 188-197.

Ramakrishna, A., Tam, H.M., Wani, S.P., Long, T.D. (2006). Effects of mulch and soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crops Research, 95, 115-125.

Rangel, A., Domont, G. B., Pedrosa, C., Ferreira, S. T. (2003). Functional properties of purified vicilins from cowpea (*Vigna unguiculata)* and pea (*Pisum sativum*) and cowpea protein isolate. Journal of Agricultural and Food Chemistry, 51**,** 5792-5797.

Rathore, A.L., Pal, A.R., Sahu, K.K. (1998). Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. Journal Science Food Agriculture, 78, 149-161.

Rashid, M.A., Zhang, X., Andersen, M.N., Olesen, J.E. (2019). Can mulching of maize straw complement deficit irrigation to improve water use efficiency and productivity of winter wheat in North China Plain. Agricultural Water Management, 213, 1-11.

Rees, H.W., Chow, T.L., Loro, P.J., Lovoie, J., Monteith, J.O., Blaauw, A. (2002). Hay mulching to reduce runoff and soil loss under intensive potato production in Northwestern New Brunswick, Canada. Canadian Journal of Soil Science, 82, 249-258.

Ribeiro, R.V., Santos, M.G., Souza, G.M., Machado, E.C., Oliveira, R.F., Angelocci, L.R., Pimentel, C. (2004). Environmental effects on photosynthetic capacity of bean genotypes. - Pesquisa Agropecuaria Brasileira, 39, 615-623

Robertson, M., Gaydon, D., Latta, R., Peoples, M., Swan, A. (2004). Simulating lucerne/crop companion farming systems in Australia. In: Proceedings of the 4th International Crop Science Congress, Australian Society of Agronomy, Brisbane.

Rockstrom, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., BBruggeman, A., Farahani, J., Qiang, Z. (2010). Managing water in rainfed agriculture-the need for a paradigm shift. Agricultural Water Management, 97, 543-550.

Rockstrom, J., Barron, J. (2007). Water productivity and rainfed systems: overview of challenges and analysis of opportunities in water scarcity prone savannahs. Irrigation Science, 25, 299-311.

Rockstrom, J., Barron, J., Fox, P. (2003). Water productivity in rainfed agriculture: Challenges and opportunities for smallholder farmers in drought prone agroecosystems. In : Kilne, J.W., Barker, R., Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement, CAB International

Rockstrom, J., Barron, J., Fox, P. (2002). Rainwater management for increased productivity among smallholder farmers in drought prone environments. Physics and Chemistry of the Earth, 29, 949-959.

Rosegrant, M.W., Cai X., CLINE, S.A. (2002). The role of rainfed agriculture in the future of Global Food Production. IFPRI, Environment and Production Technology Division Discussion Paper. 90.

SARI Savanna Agricultural Research Institute (SARI) (2012). Production guide on Cowpea (*Vigna unguiculata* L. Walp). http://www.google.co.za/amp/s/csirsavannah.wordpress.com/2012/12/04/production-guide-on-cowpea-vigna-unguiculata-l-walp/amp/ [Accessed 06/07/2016]

Schwartz D.B. (2019). All you need to know about mulches. Bobvila.http;//www.bobvila.com/articles/types-of-mulch [Accessed 22/03/2019]

Seshuhla, R.S. (2009). Mulches in smallholder maize systems in the Limpopo Province of South Africa: Untangling the effects of Nitrogen through experimentation and simulation. Adelaide: University of Adelaide, Australia.

Sekhon, N.K., Hira, G.S., Sidhu, A.S., Thind S.S. (2005). Response of soybean to wheat straw mulching in different cropping seasons. Soil Use Management, 21, 422-426.

Shan, L., Chen, G.L. (1993). The Theories and Practices of Dry-land Agriculture in Loess Plateau. Beijing: Scientific Publisher.

Singh, B. B., Ajeigbe, H. A., Tarawali, S. A., Fernandez-Rivera, S., Abubakar, M. (2003). Improving the production and utilization of cowpea as food and fodder. Field Crops Research, 84 (1-2), 169-177.

Singh, B.B., Mohan, D.R., Dashiel, K.E., Jackai, L.E.N. (1997). Advances in Cowpea Research, IITA, Ibadan: International Institute of Tropical Agriculture.

Soil Classification Working Group. (1991). Soil Classification – A Taxonomic System for South Africa. Pretoria: Department of Agricultural Development, South Africa.

Solomon, S. (2010). Disadvantages of mulch. Walden Effect. http://www.waldeneffect.org/blog/Disadvantages_of_mulch/ [Accessed 17/11/2017].

Subrahmanvian, K., Zhou, W.J. (2008). Soil temperature associated with degradable, non-degrdable plastic and organic mulches and their effect on biomass production, enzyme activities and seed yield of winter rapeseed (*Brassica napus* L.). Journal of Sustainable Agriculture, 32, 611-627.

Tarawali, S.A., Singh, B.B., Peters, M., Blade, S.F. (1997). Cowpea haulms as fodder. In: Singh, B.B., Mohan Raj, DR., Dashiel, K.E., Jackai, L.E.N. (Eds.), Advances in Cowpea Research. Ibadan: International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS).

Tariq, J.A., Khan, M.J., Haq, I. (2001). Effect of mulching on root zone moisture content and yield of different sunflower varieties under rain-fed conditions. Journal of Engineering and Applied Science, 20(1), 101-104.

Thorburn, P.J., Probert, M.E., Robertson, F.A. (2001). Modelling decomposition of sugarcane surface residues with APSIM-Residue. Field Crops Research, 70, 223-232.

Tan, X.H. (2014). Effects of ceramsite mulching on soil water content and temperature. Advanced Materials Research, 955-959, 3177-3180.

Teame, G., Alemtsehay, T., Berhanu, A.A. (2017). Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (*Sesamum indicum* L.). International Journal of Agronomy, 6, 1-6.

Turk, K.J., Hall, A.E. (1980). Drought adaptation of cowpea: influence of drought on plant water status and relation with seed yield. Agronomy Journal, 72, 421-427.

UNEP (United Nations Environment Programme). (2007). Global environment outlook GEO-4: Environment for Development. Nairobi: United Nations Environment Programme.

Van Rensburg, J.W.S., Van Averbeke, W., Slabbert, R., Faber, M., Jaarsveld, P., Van Heerden, I., Wenhold, F., Oelofse, A. (2007). African leafy vegetables in South Africa. Water S.A, 33 930, 317-326.

Verma, M.L., Acharya, C.L. (2004a). Soil moisture conservation hydrothermal regime nitrogen uptake and yield of rain-fed wheat as affected by soil management practices and nitrogen levels. Social Soil Science, 52(1), 69-73.

Verma, M.L., Acharya, C.L. (2004b). Effect of nitrogen fertilization on soil-plant-water relationships under different soil moisture conservation practices in wheat. Social Soil Science, 52(1), 105-108.

Vorosmarty, C.J., McIntyre, P.B., Gessener, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Leirmann, C., Davies, P.M. (2010). Global threats to human water security and biodiversity. Nature, 467, 555-561.

Watson, G.W., Kupkowski, G. (1991). Effects of deep layer of mulch on soil environment and tree root growth. Journal of Arboriculture, 17(5), 9.

Wang, F.X., Feng, S.Y., Hou, X.Y., Kang, S.Z., Han, J.J. (2009). Potato growth with and without plastic mulch in two typical regions of Northern China. Field Crops Research, 110(2), 123–129.

Yan, Q., Dong, F., Lou, G., Yang, F., Lu, J., Li, F., Zhang, J., Li, J., Duan, Z. (2018). Alternate row mulching optimizes soil temperature and water conditions and improves wheat yield in dryland farming. Journal of Integrative Agriculture, 17(11), 2558-2569.

Yang, J., Mao, X., Wang, K., Yang, W. (2018). The coupled impact of plastic film mulching and deficit irrigation on soil water/heat transfer and use efficiency of spring wheat in Northwest China. Agricultural Water Management, 201(C), 232-245.

Zeng, Z., Peng, L., Piao, S. (2018b). Multi-scale evapotranspiration of summer maize and the controlling meteorological factors in north China. Agricultural and Forest Meteorology, 216, 1-12.

Zhang D.M., Chi X.F., Huang E.K., Zhang J. (2008). Analysis of adverse effects on maize yield decreases resulted from plastic film mulching dryland. CSAE, 24, 99-102.

Zhang, X., Pei, D., Hu, C. (2003). Conserving groundwater for irrigation in the North China Plain. Irrigation Science. 21, 159-166.

Zhang, X.Y., Chen, S.Y, Dong, P., Liu, M.Y., Yong, S.H. (2005). Evapotranspiration, yield and crop coefficient of irrigated maize under straw mulch. Pedosphere, 15 (5), 576-584.

Zhang, Q.T., Ahmed, B.O.A., Inoue, M., Saxena, M.C., Inosako, K., Kondo, K. (2009). Effects of mulching on evapotranspiration, yield and water use efficiency of Swiss chard (*Beta vulgaris* L. var. *flavescens*) irrigated with diluted seawater. Journal of Food Agriculture and Environment, 7, 650–654.

Zhang, X., Qin, W., Chen, S., Shao, L. (2017). Responses of yield and WUE of winter wheat to water stress during the past three decades – A case study in the North China Plain. Agricultural Water Management. 179, 47-54.

Zhang, P., Wei, T., Cai, T., Ali, Shahzad., Han, Q., Ren, X., Jia, Z. (2017). Plastic film mulching for enhanced water use efficiency and economic returns from maize fields in semi-arid China. Frontiers in Plant Science,8, 512-528.

Zhang, F., Zhang, W.,Qi, J., Li, F.M. (2018). A regional evaluation of plastic film mulching for improving crop yields on the Loess Plateau of China. Agricultural and Forest Meteorology, 248, 458-468.

Zhai, S & Liang, Yinli & Zhang, X & Wang, J & Dai, Q & Liu, H. (2008). Effects of soil mulching on cucumber quality, water use efficiency and soil environment greenhouse. Transactions of the Chinese Society of Agricultural Engineering, 24(3), 67-71.

Zhao, S.L., Li, F.M., Wang, J. (1995). On the development of water harvesting agriculture in the semiarid area northwest China. Acta Botanica Boreal Occident Sinica, 15 (8), 9–13.

Zhao, X., Dai, T., Jiang, D., Cao, W. (2007). Leaf senescence and grain filling affected by post-anthesis high temperatures in two different wheat cultivars. Plant Growth Regulations, 51, 149-158.

Zhao, Y.G., Pang, H.C., Wang, J., Huo, L., Li, Y.Y. (2014). Effects of straw mulch and buried straw on soil moisture and salinity in relation to sunflower growth and yield. Field Crops Research, 161, 16-25.

Zhao, Y., Zhai, X., Wang, Z., Li, H., Jiang, R., Hill, R.L., Si, B., Hao, F. (2018). Simulation of soil water and heat flow in ridge cultivation with plastic film mulching system on the Chinese Loess Plateau. Agricultural Water Management, 202, 99-112.