ASSESSING THE POTENTIAL OF CONSERVATION AGRICULTURE TO OFF-SET THE EFFECTS OF CLIMATE CHANGE ON CROP PRODUCTIVITY USING CROP SIMULATIONS MODEL (APSIM)

BY

FREDRICK BESA MWANSA

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LUSAKA

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DECLARATION

I, Fredrick Besa Mwansa, do hereby declare that this dissertation is my own work and to the best of my knowledge has never been submitted for the award of a degree, diploma or other qualification to this or any other University.

Signature……...

Date……..……

CERTIFICATION OF APPROVAL

The dissertation of Mr. FREDRICK BESA MWANSA is approved as fulfilling the requirements for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

Examiner	**Signature**	**Date**
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ABSTRACT

Agriculture in sub-Saharan African region has depended mainly on rainfall since 1990s and crop production has faced negative impacts of extreme climate events which are believed to be manifestations of long term climate change. In addition, maize (*Zea mays L.*) productivity has continued to decline over the past years from 2.5 tons ha^{-1} in 1964 to 1.5 tons ha^{-1} in 2013. This is largely due to continuous cultivation, often in mono-cropping with little or no inputs and absence of effective Conservation Agriculture (CA). A field experiment for this study was setup on the already established CA long-term trial at Msekera Research Station in Chipata Eastern Province of Zambia. The experiment comprised of different tillage techniques; zero tillage (dibble stick), minimum tillage (animal traction direct seeding), basins (Chaka hoe) and conventional practices (mouldboard ploughing and, ridges and furrow) that were compared on productivity maize (*Zea mays L.*). The experimental design used was a split plot with CA and CT treatments as main. During the 2014/15 season CA long-term trial was used with the above mentioned experimental design with fertilizer application rates of 165 kg ha^{-1} for Compound D ($10N:20P_2O_5:10K_2O$) at planting and 200 kg ha^{-1} of Urea (46%N) with two (2) split applications. There was a significant difference of 1802 kg ha^{-1} on observed grain yield in 2014/15 season compared between Conventional Tillage (CPM2) ridge and furrow and Conservation Agriculture (DS-MC) treatments. CA treatments had maize leaves with greener phenological appearances from 24 to 60 days after planting (DAP). Agricultural Production Simulation Model (APSIM) was used to simulate the long-term effect of climate change on maize productivity using temperature rise at +1.0 ^oC, +2.0 ^oC, and +3.0 ^oC and rainfall increase and decrease of 11.3% as climate change scenarios. Calibration of APSIM model was done using Sc501 maize cultivar and data on soil N and water, bulk density, crop phenology, weather, and management information. While validation of model was done using crop phenology, soil water and N, Stover yield, and economic maize grain yield using long-term trials for 2014/15 season. Statistically, Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRME) was used to assess the performance of the model and the prediction were 22.57% for maize grain yield and 8.6% for soil water results for both measured and simulated outputs and that represented fair to excellent performance of the model. On the contrary, the model over predicted the biomass yield compared to observed results with an average of 73% RMSE that represented poor performance of the model. Soil water simulation was used in this study in relation to crop yield. The model also predicted that 28 growing seasons out of 85 will have below average maize grain yield mostly to affect the conventional tillage practices. The APSIM model further simulated that crop yield will not be affected by decrease in rainfall but increase in temperature as a climate change scenario. In addition, the model simulated that decreasing annual rainfall by 11.3% as climate scenario increased maize grain yield under CA treatments by 4% (171 kg ha^{-1}). While increasing temperature by 3.0 ^oC reduced maize grain yield by 31% (1278 kg ha^{-1}) for CT treatments. Generally, results from both observed and simulated outputs revealed that CA increased crop yields, water infiltration and storage. Furthermore, the study proved that CA has the potential to off-

set the effects of climate change on crop productivity both from measured observations and through crop simulations model.

DEDICATION

This study is dedicated to my late parents Vitaliano Mwashya Mwansa and Petronella Besa for being an inspiration to me and my wife Mercy Kachikoti Banda and my two children Chisha and Mwaka for their support, counsel and encouragement during the execution of this study.

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LIST OF ABREVIATIONS

ANOVA	Analysis of variance
APSIM	Agricultural Production Systems Simulator
BAM	Conservation Agriculture Basins with Maize as a sole crop
BD	Bulk density
CA	Conservation Agriculture
CPM 1	Conventional Practice with Maize as a sole crop (Mouldboard plough)
CPM2	Conventional Practice with Maize as a sole crop (Ridge and furrow)
CT	Conventional Tillage
CERES	Crop Environment Resource Synthesis
CIMMYT	International Maize and Wheat Improvement Center
cm	Centimeters
C:N	Carbon Nitrogen ratio
DAS	Days after sowing
DM	Dry matter
DIS-M	Conservation Agriculture Dibble Stick with Maize as a sole crop
DSM	Conservation Agriculture Direct Seeder with Maize as a sole crop
DS-M/C	Conservation Agriculture Direct Seeding Maize/Cowpea intercropping
DS-MC	Conservation Agriculture Direct Seeding Maize-Cowpea rotation
DS-CM	Conservation Agriculture Direct Seeding Cowpea-Maize rotation
DS-MS	Conservation Agriculture Direct Seeding Maize-Soybean rotation
DSSAT	Decision support system for agro-technological transfer
DS-SM	Conservation Agriculture Direct Seeding Soybeans-Maize rotation
DUL	Field capacity
esw	Soil water
ET	Evapotranspiration
Expt.	Experiment
FAO	Food and Agriculture Organization
FTC	Farmer Training Centre

ha	Hectare
IITA	International Institute of Tropical Agriculture
Kg	Kilogram
UNZA	University of Zambia
LAI	Leaf area index
LL15	Permanent wilting point
m	Meter
mg	Milligram
mm	Millimeter
MAL	Ministry of Agriculture and Livestock
NDVI	Normalized Difference Vegetation Index
nm	Nanometer
NRMSE	Normalized Root Mean Square Error
NS	Not significant
R^2	Coefficient of determination
RCBD	Randomized complete block design
RMSE	Root mean square error
SAT	Volumetric water content at saturation
SOC	Soil organic carbon
SoilN	Soil nitrogen module
SoilP	Soil phosphorous module
soilWAT	Soil water module
SSA	Sub-Sahara Africa
ZARI	Zambia Agricultural Research Institute

CHAPTER ONE

1.0 INTRODUCTION

Agriculture in sub-Saharan Africa (SSA) supports between 70 and 80 percent of employment and contributes an average of 30 % of Gross Domestic Product (GDP) through crop production (Commission for Africa, 2005). Rain-fed agriculture dominates agricultural production in the SSA region covering about 97 % of total cropland, and exposes agricultural production to the risks of high seasonal rainfall variability (Calzadilla et al., 2008). Climate change has significantly affected global agriculture in the 21st century. And according to the Intergovernmental Panel on Climate Change (IPCC, 2007) assessment report that indicates most countries in SSA will experience an increase in average temperature, more frequent heat waves, more stressed water resources, desertification, and periods of heavy precipitation. A similar report (IPCC, 2001) suggested that global surface air temperature may increase by 1.4 ºC to 5.8 ºC at the end of the century. IPCC, (2007) report further revealed that the past three decades have been the warmest in history, with each decade being warmer than the preceding period. Calzadilla et al., (2008) added that measureable indicators have proved that the African continent is warmer than it was 100 years ago. In fact, the six warmest years in recent decades in Southern Africa have all occurred since 1980 (Yanda and Mubaya, 2011). Furthermore, future climate change may present an additional challenge to agricultural production in SSA region (Calzadilla et al., 2008). Future impacts are projected to worsen as the temperature continues to rise and precipitation becomes more unreliable. In Zambia, extreme climatic events experienced have had negative impacts not only on small-scale agriculture but also on the national economy at large (Lekprichakul, 2008). The economic impacts of droughts in Zambia is evident from the 2004/05 droughts that led to a 60% loss of maize yields. However, in most parts of Zambia including the Eastern Province, seasonal soil moisture deficit due to low rainfall and high potential evapotranspiration are the major constraints to maize (Zea mays L.) production (Shitumbanuma, 2008).

Climate change factors such as increased temperature and erratic rainfall patterns are being addressed through increased employing of technologies such as Conservation Agriculture that increase water infiltration and reduce moisture evaporation from the soil (Marongwe et al., 2011). Conservation agriculture (CA) is a crop management system based on three principles; minimum soil movement, soil surface cover with crop residues and/or living plants and crop rotations to avoid pest and diseases (Thierfelder *et al.*, 2014). The principles of CA appear to have extremely wide adaptation, and CA systems are currently used by smallholder farmers under a wide range of conditions and with numerous crops (Thierfelder et al., 2014). Nevertheless, the techniques to apply the principles depend on climate, soil and farmer circumstances. The primary rationale of CA is to protect the natural resources for agriculture thereby sustaining and maintaining agricultural productivity in long run (Marahatta et al., 2014). CA generally does not work well without residues, as many benefits come from surface mulch (Thierfelder and Wall, 2014). However, most smallholder farmers in Eastern Province of Zambia manage mixed crop-livestock systems and depend on the residues for fodder during the dry season. To reduce this conflict, CA needs to be started on a small part of the farm and adequate nutrients supplied. In CA systems the residues protect the soil surface, water infiltration is increased and water storage improved (Mupangwa et al., 2013). Also, under CA systems there are more soil pores because of the increased biological activity with continuous residue cover and because the pores are not continually broken down by tillage (Thierfelder and Wall, 2014). Crop rotation in CA systems is essential as it contributes to reduction in pests and diseases in the cropping system and to control weeds by including smothering crop species (e.g. cowpeas) or green manure cover crops (Thierfelder et al., 2014). Further, crop rotation in CA systems may also give benefits in terms of improved soil quality, better distribution of nutrients in the soil profile and to increased biological activity (Mupangwa et al., 2012).

The other primary aim of CA is to reduce soil movement and soil disturbances and ensures that soil moisture is conserved and more water becomes available for crop growth (Thierfelder and Wall, 2010a). Overall, CA systems have a higher adaptability, minimized runoff and soil erosion as well as greater soil moisture-holding capacity. According to report by Hobbs P.R. et al., (2007) revealed that benefits of CA are a

suggested improvement on conventional tillage, where no-tillage, mulch and rotations significantly improve soil properties and other biotic factors. Mupangwa et al., (2012) reported that the long-term benefits of CA includes; increased soil organic matter (SOM) resulting in better soil structure, higher cation exchange capacity and nutrient availability, and greater water-holding capacity. Others are increased and more stable crop yields, reduced production costs, and increased biological activity in both the soil and the aerial environment leading to improved biological soil fertility and pest control. Therefore, all these CA benefits culminate into improved crop yield, soil health, and soil water storage increased soil biological activities. The soil moisture conditions in rooting zones through growing seasons under CA are better than under conventional tillage (Kassam et al., 2009).

There is a long history of mono-cropping and inappropriate inorganic fertilizer use in Zambia. This has led to land degradation and consequently lower soil productivity. And according to FAO, (2013) the national yield average for maize (Zea mays L.), which is the main staple food crop in Zambia has declined from 2.5 tons ha^{-1} in 1964 to 1.5 tons ha^{-1} in 2013. Using the same hybrids varieties yields of a well-managed maize (Zea mays L.) crop, especially in research stations and on commercial farms average 6 to 8 tons ha^{-1}. Increasing concerns about the future of agriculture in SSA in light of accelerating soil degradation (Oldeman et al., 1990; Kumwenda et al,. 1998; Sanginga and Woomer, 2009) and potential threats of climate change (Lobell et al., 2008), have increased the need for new and more adapted cropping systems that increase production, whilst conserving the natural resource base (Wall, 2007; Kassam et al., 2009; Thierfelder and Wall, 2009). CA is one of the 'greener' solutions currently being discussed (Gilbert, 2012) as a potential cropping system that can mitigate the negative effects of declining soil fertility and climate change, under a range of farming systems (Hobbs, 2007; Kassam et al., 2009). In coping with these challenges, farmers in the eastern region of Zambia have developed or adopted various types of soil and water conservation technologies through the intervention of government change agents and other collaborating partners such as the CG Centers and FAO. Some of these technologies include the use of water harvesting planting basins locally known as Gampani which harvest water in the cropping field.

In order to understand the future effects of the aforementioned climate variability and provide solution, Agricultural Production Simulation Model (APSIM) was used in the study. Agricultural systems models worldwide are increasingly being used to explore options and solutions for food security, climate change adaptation and mitigation and carbon trading problem domains (Keating et al., 2003). And according to (McCown et al., 1996), APSIM simulates the dynamics of crop growth, soil water, and nitrogen and soil carbon in a farming system. APSIM is one such model that continues to be applied and adapted to this challenging research agenda (Shamudzarira and Robertson, 2002). It operates on daily time steps and when driven by long-term or current daily weather data, can be used to predict the impact of seasonally variable rainfall, both amounts and distribution, on the climate-induced risk associated with a range of crop, water and soil management strategies (McCown et al., 1996). And according to Keating et al., (2003), who reported that from its inception twenty years ago, APSIM has evolved into a framework containing many of the key models required to explore changes in agricultural landscapes with capability ranging from simulation of gene expression through to multi-field farms and beyond. Furthermore, agricultural simulation models have an important role in informing farmer practice (Hochman et al., 2009b), breeding strategies (Cooper et al., 2009) and government policy (Bezlepkina et al., 2010) that aim at addressing challenges such as food security and climate mitigation and adaptation. The demand for tools that can assist in the analysis of complex problems are more pronounced than ever. For this study APSIM was preferred as a result of its ability to provide accurate simulation of actual crop yields across a range of soil types and seasons when properly calibrated.

Therefore, CA systems offers potential solutions to mitigate the effect of climate variability on crop productivity, reduce the risk of crop failure, and secure livelihood. (Thierfelder and Wall, 2010). Investigations conducted in Zambia and Zimbabwe by CIMMYT on different maize based CA systems has revealed that CA increases water infiltration and available soil moisture (Mupangwa, 2014). The increased soil moisture will enable crops to overcome seasonal dry spells, mitigate the effects of drought, (Thierfelder and Wall, 2010).

1.1 Justification of the study

Climatic models suggest that the sub-Saharan African region will be strongly affected by the changes in climate; they predict higher temperatures and an increased frequency and severity of drought, which will prejudice crop production if there is no adaption or change of the existing cropping systems. Climate change and agriculture are interrelated processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, precipitation and the interaction of these elements. CA technology was preferred for this simulation as it is able to perform even in seasons with inadequate rainfall, which is the primary source of variability that generates risks in agricultural production.

1.2 Objective

1.2.1 Main Objective

The objective of this study was to assess the potential of CA to off-set the effects of increased temperature and reduced rainfall on crop productivity using CA long term on-station trial at Msekera Research Station using the APSIM crop simulation model.

1.2.2 Specific Objectives

The study had the following specific objectives:-

i. To determine the effect of conventional and CA practices on maize yield and Normalized Difference Vegetation Index (NDVI)
ii. To evaluate the effects of rainfall and temperature changes on crop yield under CA predicted using the APSIM model
iii. To evaluate the effects of rainfall and temperature changes on soil water accumulation under CA using the APSIM model

CHPATER TWO

2.0 LITERATURE REVIEW

2.1 Conservation Agriculture

Conservation Agriculture as a cropping system is aimed at addressing the problems of poor agricultural productivity and soil degradation resulting from poor agronomic/management practices that deplete soil organic matter and nutrient (Giller *et al.,* 2009). Several authors have highlighted the benefits and challenges of CA (Verhulst *et al.,* 2010, Govaerts *et al.,* 2007, Haggblade and Tembo, 2003). The cumulative effects of the three basic principles of CA which include minimal soil disturbance, permanent ground cover, and crop rotation/associations are discussed as one since these interact to provide the benefits (Thierfelder, 2010).

Studies done in other parts of Africa and the world in general revealed that minimum tillage coupled with residue retention improves soil structure by increasing the soil particle aggregation resulting from microbial organic matter decomposition (Verhulst *et al.,* 2010). It is known that addition of organic substrates to the soil improves its structure (Hobbs, 2007). Crop residue retention also increases the resistance of the soil to raindrop impact due to aggregation thus reducing soil erosion. The overall result is enhanced capacity of the soil to retain and transmit water, organic and inorganic substances, diffusion of gasses especially oxygen and carbon dioxide and the ability to support vigorous root growth and development. The soil conditions mentioned above promote microbial growth and proliferation which in turn influences soil fertility positively (Gupta, 1998).

Crop rotation is one of the pillars of CA as it improves soil fertility. For example deep rooted crops provide a better soil structure, aggregation (from root decomposition) as well as pore continuity resulting in increased infiltration rates and soil moisture content (Thierfelder, 2010). Other benefits of crop rotation include better nutrient distribution in the soil profile resulting from full exploitation of the root zone in different layers with crops of differing rooting depths (Giller *et al.,* 2009).

Hobbs (2007) found significant positive effects on soil properties from an 11 year experiment in semiarid North China under minimum tillage and residue retention. The same author reported that residue retention coupled with reduced tillage significantly increased soil organic matter content and improved nutrient status, increased macro-aggregate stability, higher proportions of macropores and mesoposes as well as enhanced soil water storage. However, the other authors have reported that minimum tillage does not always result in improved soil chemical, physical and biological properties. In this regard, minimum tillage has been reported to be associated with higher bulk densities, lower water permeability and higher soil penetration resistance (Verhulst *et al.,* 2010, Blanco-Canqui and Lal, 2007).

Ground cover promotes an increase in biological diversity not only below ground but also above ground; the number of beneficial insects was higher where there was ground cover and mulch (Kendall *et al.* 1995; Jaipal *et al.* 2002), and these help keep insect pests in check. Interactions between root systems and rhizobacteria affect crop health, yield and soil quality. Release of exudates by plants activate and sustain specific rhizobacterial communities that enhance nutrient cycling, nitrogen fixing, biocontrol of plant pathogens, plant disease resistance and plant growth stimulation. According to Sturz and Christie (2003) ground cover would be expected to increase biological diversity and increase these beneficial effects.

According to Thierfelder and Wall (2011), crop residues consist of dead plant parts, or Stover, that remain from previous crops, including green manure cover crops, and may be supplemented with dried weeds or other imported plant material. Soil cover is one of the most critical factors in ensuring the success of Conservation Agriculture (Thierfelder and Wall, 2011). In conventional agricultural systems, residues are usually fed to animals, taken off the field for other uses, incorporated or burned. In many places communal grazing rights are practiced, and protecting the residues on the fields from free roaming animals can entail considerable conflicts (Thierfelder and Wall, 2011). However, farmers managing CA systems derive huge benefits from surface residue retention which makes keeping them on the fields very worthwhile, and in some

communities have found ways to overcome the problems of communal grazing rights (Thierfelder and Wall, 2011).

2.2 Conventional Farming Practices

2.2.1 Conventional Farming Systems

Thierfelder *et al.,* (2013) reported that conventional farming is generally not considered a CA seeding system due to considerable soil movement during land preparation. In this system, farmers create ridges and furrows using hand-held hoes.

2.2.1.1 Ridge and Furrow System

Conventional moldboard ploughing (CMP) is normally performed using a single-row moldboard plow to a shallow depth (10–15 cm). Plowing completely inverts the soil and prepares a clean seedbed with fine tilth, depending on the soil type. Farmers plow their land either during the off-season (July–August) or at the onset of the cropping season in November, once the soil is soft after the first rains (Thierfelder *et al.,* 2013).

Traditional ploughs turn the soil over in one direction, with the ploughshare and moldboard to the right. This means that the plough cannot return along the same furrow. Instead, ploughing is done in a clockwise direction around a long rectangular strip (a *land*). After ploughing one of the long sides of the strip, the plough is removed from the ground, moved across the unploughed *headland* (the short end of the strip), then put back in the ground to work back down the other long side of the strip. The width of the ploughed strip is fairly narrow, to avoid having to drag the plough too far across the headland. This process has the effect of moving the soil in each half of the strip one furrow's-width towards the centre line (FAO, 2010).

From East Africa to the Cape Town, millions of tons of top soil are turned and churned with hoes, ploughs and harrows every year before or after the onset of the rains in a hugely destructive and wasteful effort to establish crops and eradicate weeds (FAO, 2010). For almost a century now conventional farming practice has persisted and draws strong connections to ancestors' way of farming. Indeed, the plough introduced to Africa

by colonists at the turn of the 20th century predates Christianity by nearly 2000 years (FA0, 2010).

2.2.1.2 Mouldboard Plough on Flat System

Conventional farming systems in southern Africa are based on the moldboard plough, or on small hand hoes locally known as *'Kambwili'* for land preparation and planting (Thierfelder *et al.,* 2012). Ploughing is normally done in October/November. According to Thierfelder et al. (2012), crop residues are being grazed, burned or removed and in some instances incorporated by the plough or hand hoe.

2.2.2 Land Degradation

Land degradation is a process in which the value of the biophysical environment is affected by a combination of human-induced processes acting upon the land. It is viewed as any change or disturbance to the land perceived to be deleterious or undesirable (FAO, 1994). Estimates of land degradation in Africa range from alarming to catastrophic and are difficult to verify. Many experts suggest that 70% of agricultural land suited for raising livestock or crops is already severely degraded (Aagaard, 2014). Whatever the facts, any observant traveler can notice the injurious treatment of soil on a massive scale. And in Zambia, it is impossible to ignore the thousands of hectares of formerly cropped fields that have been abandoned and have reverted to scrub or grass (FAO, 1994).

While agricultural productivity has risen dramatically, the cost in land degradation has been high. Large areas of the SSA region's cropland, grassland, woodland and forest are now seriously degraded (FAO, 1994). Even though water and wind erosion are the major problems, also salinity, sodicity and alkalinity are widespread. Furthermore, water tables have been over-exploited; soil fertility reduced; and forests have been cleared for urban expansion, erosion has been a common result in Zambia (Aagaard, 2014)). Finally, urban expansion has become a major form of land degradation, removing large areas of the best agricultural land from production (UNEP, 1994). The effect of these forms of land degradation on cereal production has so far been masked by the increasing levels of agricultural inputs that are used (FAO, 1994). However, production of other crops, such

as pulses, roots and tubers, has now begun to decline. It is no coincidence that these crops are grown on land with low production potential, where rates of land degradation are highest. (UNEP, 1994). The key environmental challenges that require effective concerted effort engagement are Soil and land degradation (Aagaard, 2014). This is a common and localized problem in most districts in Zambia. The main cause of the problem is poor farming practices (conventional tillage), population pressure and lack of diversification of sources of livelihoods (UNEP 1994). Also heavy use of chemical fertilizer to produce maize, which is the staple food source in the country has led to serious soil and land degradation, reduced production and land abandonment in most some cases (FAO, 1994).

2.3 Conservation Agriculture Practice

2.3.1 Seeding Crops in CA

Soil tillage leads to the breakdown of soil structure and land degradation and is therefore not sustainable (Johansen et al., 2012). However to be able to plant into unploughed soil, special methods or equipment are necessary. Both manual and mechanical systems are available to small-holder farmers for sowing crops under Conservation Agriculture (Johansen et al., 2012; Sims and Kienzle, 2015).

2.3.1.1 Manual Systems

According to Thierfelder and Wall (2013) direct seeding is also referred to as seeding with a dibble stick (pointed stick), jab-planter and animal traction planter. There are currently three direct seeding systems used in Southern Africa. Seeding with a dibble stick (a pointed stick) where farmers make two holes and place seed and fertilizer. A more mechanized version is the Jab-planter (Matraca) that places seed and fertilizer in planting holes created by the implement (Thierfelder and Wall, 2013; Sims and Kienzle, 2015).

Manual seeding of crops into residues is relatively easy and can be done by several methods: with a hoe or pointed stick, digging of basins or zai pits, or using equipment such as the jab planter (Thierfelder and Wall, 2013). The simplest of these are the hoe

and a pointed stick: small holes are made at the required spacing and seed placed in these, preferably with fertilizer or manure placed in another hole a few centimeters away (Thierfelder and Wall, 2013).

Figure 1: Using a dibble stick to seed into maize residues

2.3.1.1.1 Planting Basins

Basins are small holes of approximately 15 cm x 15 cm x 15 cm deep in rows 75-90 cm apart and with 50-60 cm between basins (centre to centre) in the row. Mupangwa et al, (2011) reported that basins are dug manually with a hoe during the winter period so that labour is distributed over a longer period and the crop can be planted with the first effective rains. Twomlow et al., (2008) emphasized that basins leave over 90% of the soil area undisturbed, capture run-off water and benefit from precise fertilizer placement. In addition, Twomlow et al., (2008) noted that basins should be made in the same place each year and, after initial formation; do not need as much labour to re-form. Because of the concentration of water and initial rains in the basins, the benefits can be apparent in the first season. However, basins do require considerable labour especially in the first dry season when soils can be very hard (Mazvimavi and Twomlow, 2009; Ndlovu et al., 2014).

Figure 2: Planting basins dug in winter period ready for planting with the first rains

2.3.1.1.2 Jab-planter (Matracas)

The jab-planter used for CA is a manual implement with two points that are pushed into the moist soil through the mulch, and opened to release the seed and fertilizer. According to Thierfelder et al. (2014), the jab planter is quicker than hoe or pointed stick methods once the technique is mastered, and seed and fertilizer can be placed with more precision. However, experience is needed to be able to seed well and accurately, and in wet clay soils, seeding can be difficult as soil sticks to the points. Jab planters are also more expensive than hoes or pointed sticks, and are still difficult to purchase Thierfelder et al. (2014).

Figure 3: Seeding with a Jab-Planter on a residue covered field

2.3.1.2 Animal Traction Systems

2.3.1.2.1 Seeding behind ripper tines

According to Sims and Kienzle (2015) and, Thierfelder and Wall (2013) ripper tines are attachments fitted to the plough frame. They were developed to open furrows for moisture capture or to break superficial compacted layers, but in CA they work well to open planting furrows. The animal-drawn Magoye ripper works at a shallow depth (10-15 cm) and, after making the rip line seed and fertilizer are placed manually in the furrow and covered (Thierfelder and Wall, 2013). Other ripper tines such as knife rippers can be found in the region, but are not as common. Thierfelder and Wall (2013) noted that in the first year of CA, if there is a plough pan, then a sub-soiler can be used to break the pan: the *Palabana* sub-soiler for the case of Zambia is efficient and can work up to 25 cm. The furrow formed by the sub-soiler may be suitable for seeding or may need to be reformed.

2.3.1.2.1 Animal traction direst seeders

Direct seeders are designed to seed into surface mulch in untilled soil (Thierfelder and Wall, 2013). The implement has separate seed and fertilizer hoppers and a cutting disk (coulter). The coulter cuts through the residues, a ripper tine opens a furrow, and the seed and fertilizer are placed in the furrow– all in a single operation (Thierfelder and

Wall, 2013; Sims and Kienzle, 2015). Seeder units are manufactured for both oxen and donkeys for most smallholder farmers in sub-Saharan Africa.

2.3.2 CA Cropping Systems

2.3.2.1 Intercropping System

A crop association practice where the main crop (commonly maize in Southern Africa) is inter-planted with other crops. Grain legumes (e.g. cowpea, pigeon pea, common beans, and groundnuts) are the most prevalent intercropping species in Southern Africa but green manure cover crop (GMCCs) such as velvet beans (*Mucuna pruriens*), lablab (*Lablab purpureus*) and fish bean (*Tephrosia vogelii*) are also used (Thierfelder *et al.*, 2013).

Thayamini and Brintha, (2010) reported that legumes in maize based cropping systems are considered to be better alternatives for securing nitrogen economy and increasing yield of maize besides bonus yield, greater productivity per unit time and space and higher net returns of intercropping system over monoculture. The effect on N input from symbiotic nitrogen fixation into the cropping system and reduction of negative impact on the environment are eminent Jensen, (1996). Intercropping delivers a fast and good ground shield and also allows the roots to adventure soil nutrients at several depths (Steiner, 1991). The conventional farming practice seems to have unconsciously cropping system with a view of maintaining the soil richness because intercropping produces a constant and workable agro-ecosystem.

Ijoyah and Fanen (2012) further reports that the choice of crop combination is key to successful intercropping. Incompatibility factors such as planting density, root system and nutrient competition need to be considered (Ijoyah and Jimba, 2012). Farmers practice intercropping with a wide array of crops, consisting ordinarily of a major crop and other insignificant crops, however, it is pertinent that the selection of compatible crops be given priority as this depends on their growth habit, land, light, water and fertilizer utilization (Thayamini & Brintha, 2010). For example, when intercropping

maize with cowpea, phase planting should be considered of about 10-14 days after seeding maize crop in order to avoid competition for light.

Intercropping plays a vital role in subsistence food production in both advanced and emerging countries (Adeoye et al., 2005). Legumes can relocate fixed N to intercropped cereals through their joint growing period and this N is an imperative resource for the cereals (Bhagad et al., 2006). In a general note, Shafik and Soliman (1999) put it that intercropping may lead to overall yield advantage most especially in conservation agriculture practice.

2.3.2.2 Crop Rotation System

Rotation is the repetitive sequence of crops in the same place in a defined order. Farmers in Southern Africa generally practice rotations between maize and leguminous crops (cowpeas, soybeans, groundnuts, and common beans), green manure crops and non-leguminous cash crops such as cotton, sunflower and cassava (Thierfelder *et al.,* 2013).

Crop rotation is one the three pillars of CA, but is often the last to be incorporated into the system by most farmers, often because of a lack of adequate markets for alternative crops (Thierfelder and Wall, 2010a). Although one of the main reasons for crop rotation in CA systems is to avoid problems of pests and diseases harbored on the residues (Baudron *et al.,* 2012b), there may also be marked yield benefits associated with crop rotation under CA conditions. According to Wall *et al.,* (2009) only maize grain yield in the maize phase of rotation had a full economic analysis necessary to ascertain the profitability of the rotation. The research reported that legumes are often preferred for rotations because of the benefits of biological nitrogen fixation, but non-legume crops may also benefit as maize crops as evidenced by the 10% yield increases in yield of maize in a maize-cotton rotation at Monze Farmer Training Centre (FTC) trials in Zambia conducted by CIMMYT (Thierfelder *et al.,* 2013).

2.4 Effects of CA on Smallholder Cropping Systems

According to Thierfelder *et al.,* (2013), initial research from 1988 to 2002 largely focused on the effects of CA on soil quality, such as the effects of selected CA and non-

CA systems on soil erosion, carbon, weeds and soil water dynamics. These studies from Zimbabwe highlighted that reduced tillage and mulch cover reduced erosion and increased soil moisture, which led to overall greater yields, especially in dry years. The results also showed that timing of planting and other operations was more important than the type of tillage system employed, particularly in the sub-humid parts of the country.

2.5 Effects of CA on infiltration and soil water

Rainfall distribution patterns during the growing season in Zambia are characterized by mid-season dry spells. Thus, higher infiltration rates under CA and surface crop residue retention have the potential to buffer growing crops against intermittent periods of drought stress (Thierfelder *et al.,* 2013). The effect of CA on water infiltration and soil moisture in Southern Africa has already been reported in detail by Thierfelder and Wall (2010). No-tillage and residue retention increase infiltration rates, an effect which appears almost immediately when the soil is covered with mulch. Infiltration measurements at Henderson Research Station, Zimbabwe and Monze Farmer Training Centre, Zambia with a mini-rainfall simulator showed clearly that CA treatments were able to maintain higher infiltration rates compared with conventionally plowed treatments without residue retention across sites (Thierfelder *et al.,* 2013).

The increase in infiltration rate is mostly due to an increase in biological activity, reduction in soil surface disturbance and the continuity of macropores. Similarly, studies conducted under the semi-arid conditions of Zimbabwe showed that over time CA practices improved hydraulic properties (unsaturated hydraulic conductivity and capillary sorptivity) of a clay loam soil (Mupangwa *et al.,* 2013). However, studies also showed that the effect of CA on water infiltration is mostly dependent on soil type, with the potential negative effect of water logging on granitic sandy soils, which have a tendency to accumulate too much water. Water balance studies over a 5-year period (1994/5–1998/9) on clay soils at Hatcliffe, Zimbabwe by Nyagumbo (2008) allowed water losses through runoff and evapotranspiration to be compared between a CA system in the form of mulch ripping (Magoye Ripper) and Conventional Moldboard Plowing (CMP).

Using an improved simple water balance technique derived *in situ* over five seasons (1994/5–1998/9), only 26% of the total rainfall under Conventional Moldboard Plowing (CMP) was contributed to groundwater recharge compared with 50% under CA using Magoye Ripper (Mupangwa *et al.,* 2013). Average runoff of seasonal rainfall was also reduced under MR, with only 1% of rainfall lost due to run off compared with 20% under conventional moldboard plowing (CMP). Although the difference between seasonal evapotranspiration under CMP and MR was small (51% compared to 46%) soil moisture storage within the top 45cm of soil was significantly greater under Magoye Ripper compared with conventional moldboard plowing (Mupangwa *et al.,* 2013).

In addition, field water balance modeling studies in South Africa showed that no-till systems (rip-line seeding systems without mulch retention) reduced surface runoff by 28% and increased deep drainage by 19% on a sandy clay loam soil compared to CMP (Mupangwa *et al.,* 2013). Studies on soil moisture by Thierfelder and Wall (2014) confirmed that CA treatments on an Arenosol at Henderson, Zimbabwe and a Lixisol at Monze, Zambia, had more available soil moisture than conventionally plowed treatments (Thierfelder *et al.,* 2013). The results of these studies showed that CA techniques increase soil water balance attributes when compared with conventional plowing.

Furthermore, Thierfelder and Wall (2014) reported that CA systems often result in higher water productivity compared to conventional plow-based tillage systems, by up to ± 10 kg ha^{-1} mm^{-1}, depending on seasonal rainfall patterns. Only one study has been conducted on deep drainage and leaching on a granitic sandy soil, using lysimeters, at Domboshawa Training Centre, Zimbabwe (Thierfelder *et al.,* 2013). The results suggest no-till tied ridging system resulted in 21% more deep drainage and consequent nitrate leaching than CMP, which could potentially have negative effects on plant growth (Thierfelder *et al.,* 2013).

In summary, CA generally increases water infiltration and improves available soil moisture. This can potentially reduce the negative effects of in-season dry spells, reduce run-off and provide more available water for plant growth. Nevertheless, there are also

findings that water infiltration in CA systems is dependent on soil type, with the potential negative effect of water logging on granitic sandy soils.

2.6 Effects of CA on Crop Productivity

According to Thierfelder *et al.*, (2013), significant yield benefits under CA in Southern Africa are possible, although they may be site-specific and in response to different agro-ecological environments. Studies have shown that rotation as well as appropriate fertilization is critical for CA results to become significant (Thierfelder *et al.,* 2013). This was successfully shown in component omission trials in Malawi, Mozambique and Zimbabwe (Thierfelder *et al.,* 2013). In some environments the benefits of CA started after 1–2 seasons, whereas in other environments the benefits required more seasons for effects to build up, which is in agreement with a recent meta-analysis. For example, in the high-rainfall environment of Zidyana EPA, Malawi, characterized by sandy loam soils, substantial maize yield benefits were obtained after five seasons (Thierfelder *et al.,* 2013).

This lag period between implementation and effects of CA is mainly related to the need to produce sufficient crop residues and improve degraded soil fertility, applying the right fertilizer and seed, equipment, planting at the right time and inclusion of a systematic rotation scheme (Thierfelder *et al.,* 2013). In on-farm trials in Monze, Zambia, Thierfelder *et al.,* (2013) reviewed that incremental benefits of CA systems compared to CP treatments were significant following the third cropping season, contrary to the suggestion that CA needs a very long time until yield benefits materialize.

According to Thierfelder *et al.,* (2013) who noted that although maize yield benefits in CA systems take 3–5 seasons to occur, with some exceptions in unfavorable environments, the trend is not as clear when maize is intercropped or rotated with legumes, which tend to respond less to fertility increases and water conservation. The research further highlighted that increased water accumulation in the soil can cause root rot, thereby reducing the yield of legumes (Thierfelder *et al.,* 2013). Legume yield data from Malende, Monze (Zambia) from 2007 to 2012 showed very variable results between two CA treatments and the conventional control, with significant yield differences only after the sixth cropping season (Thierfelder *et al.,* 2013).

According to Thierfelder *et al.,* (2014) reports that in low-yielding environments CA has potential to double the maize yields obtained under conventional tillage, which was previously shown by Thierfelder and Wall (2014) in a study carried out at Zimuto Communal Area, Zimbabwe. The report further outlined that under semi-arid conditions of southern Zimbabwe, CA (planting basin and rip-line seeding systems) produced 102–142% more cowpea grain compared to conventional practice in a drought year. However, in a season with above average rainfall, CA and conventional systems produced similar cowpea yields (Thierfelder *et al.,* 2013).

Maize yields under no-till with mulch retention was marginally better than under conventional tillage in a regional study on CA trials in Southern Africa. The inclusion of rotation or intercropping systems led to increased yields, and in some instances yield under CA was almost double that in conventional tillage (Thierfelder *et al.,* 2014). According to Thierfelder *et al.,* (2014) the results also highlighted the importance of legumes within a rotation and crop diversity. Substantial yield increases were observed, and in some cases maize yields following legumes were almost double that of continuous maize under no-till. At Henderson Research Station in Zimbabwe, there was a significant increase in maize yields planted after Sunnhemp after several years (Thierfelder *et al.,* 2013).

Thierfelder *et al.* (2013) reports that CA has generally been reported to increase labor use efficiency and returns per unit labor compared to conventional agriculture. For instance, significantly higher labor productivity (in kg person-day^{-1}) and returns to labor (USD person-day^{-1}) for CA were observed compared to conventional farming across low, average and high seasonal rainfall levels in Zimbabwe. Mazvimavi *et al.,* (2012) also showed that farmers practicing CA increased yields by 10–100% compared with conventional practice, depending on fertilizer rates and management, experience of the farm household and seasonal rainfall patterns.

2.7 Influence of CA on selected biological properties

2.7.1 Soil Microbial Biomass (SMB)

The populations of microorganisms are collectively known as microbial biomass (Gupta, 1998). Soil microbial biomass (SMB) represents a small portion of organic matter but it is dynamic and responds very quickly to soil management practices. The various management practices that influence populations include tillage, residue retention, crop rotation, fertilizer and pesticide application. The size of microbial biomass in the surface soil ranges from 0.25 mg/g soil in sandy soils to about 1.10 mg/g soil in an organic matter rich clay soils (Gupta, 1998). Soil microbial biomass plays an important role in the physical stabilization of soil aggregates. It reflects the soil's ability to store and cycle nutrients (Carbon, Nitrogen, Phosphorus and Sulphur) and organic matter. Maintaining soil microbial biomass (SMB) and microflora activity and diversity is cardinal for sustainable agricultural management (Gupta, 1998).

Soil management influences soil microorganism, their processes and seasonal and spatial distribution through changes in the quantity and quality of plant residues and nutrients input into the soil (Verhulst *et al.,* 2010). The rate at which organic C from plant biomass is retained is generally considered the dominant factor controlling the amount SMB in the soil (Govaerts *et al.,* 2007b). A continuous, uniform supply of C from crop residue serves as an energy source for microorganism. Shah *et al.* (2003) and Zibilske *et al.,* (2000) reported that retaining crop residue on the surface increases microbial abundance. Govaerts *et al.,* (2007b) also found a significant increase in SMB-C and N with crop rotation when retained under reduced tillage in the highlands of Mexico. However, the influence of CA practice on SMB-C is mainly confined to the surface layers of the soil.

A study conducted by Alvear et al. (2005) on Ultisol in Southern Chile found higher SMB-C and N in the top 0-20 cm layer under reduced tillage than under conventional tillage. The authors attributed the increase to the higher levels of C substrates available for microorganism growth, better soil physical conditions and higher water retention under reduced tillage. Similar results were reported by Salinas-Garcia et al. (2002)

although the effects were at the shallow depth of 0-5 cm where they were 25-50% greater with reduced tillage compared to minimum tillage. In general, Verhulst *et al.*, (2010) attributed the increased soil microbial populations to the favorable effects of minimum tillage and residue retention and reduced retention such as increased soil aeration, water conditions and higher carbon contents in the surface soil horizon.

According to Nijsingh (2007) a study done centrally in Paran, Brazil showed no clear differences in SMB content in the 0-10 cm layer between the reduced tillage and conventional fields after four years of conservation tillage. The effect of CA practices on SMB, therefore, varies and is mainly dependent on the amount and quality of crop residue retained to the soil.

2.7.2 Biological Nitrogen Fixation

Jarecki and Lal, (2003) reports that introducing legumes in rotation increases the N pool by symbiotically fixed N. Biological nitrogen fixation in conservation agriculture offers a natural and relatively inexpensive way of providing nitrogen to the plants. The process involves reducing atmospheric nitrogen by specialized microorganisms into available forms that can be absorbed by plants (Jarecki and Lal, 2003). An enzyme called nitrogenase catalyzes the breaking of nitrogen bonds and the addition of three hydrogen atoms to each nitrogen atom. Among these soil microorganisms are rhizobia bacteria which exists primarily as soil saprophytes widely distributed in the rhizospheres of plant roots (Brottomley and Myrold, 2007). They are grouped as symbiotic and asymbiotic, with examples of symbiotic being *Rhizobium, Bradyrhizobium japonicum, Sinorrhizobium meliloti* etc. these bacteria form symbiotic associations with legumes such as alfalfa, soybeans, edible beans, clover beans etc. though formation of root nodules on the host plan in which they convert atmospheric nitrogen into plant available amino nitrogen (NH_2) (Moravec *et al.*, 2011). The amino nitrogen is supplied to the host plant while the bacteria obtains essential mineral minerals and sugars hence the host plant serves as a source of energy.

However, the process of establishing a symbiotic relationship is highly specific in the sense that a specific bacterial species has one or a limited number of legumes host species. For example, rhizobium for soybeans and alfalfa are *Bradyrhizobium japonicum*

and *Sinorrhizobium meliloti* respectively. Further, the legume-rhizobium symbiotic relation is greatly influenced by farm management practices (Unkovich *et al.,* 2008) and environmental stresses. Environmental stresses affect both rhizobium and the host plant through soil acidity, extreme temperature, insufficient or excess soil moisture, nutrient deficiency (K, P, Ca, Mg, Mo, B), amount of N in the soil and inadequate photosynthesis. Optimum pH for *rhizobium* is 6-8 while temperature should be between 25-40 ^{o} C and moisture within the stress tolerance of temperature of the host plan (Gupta, 1998).

2.8 Effect of CA on Selected Soil Chemical Properties

2.8.1 Soil Reaction (pH)

Several studies have reported contrasting results on the effect of CA on soil reaction (Roldan *et al.,* 2007; Umar *et al.,* 2011; Duiker and Beegle, 2006). High pH was observed in the upper 15 cm depths in CA compared to conventional (Duiker and Beegle, 2006 and Govaerts *et al.,* 2007c). Duiker and Beegle (2006) attributed the high pH to the buffering effect of the accumulated soil organic matter in CA as well as liming. In CA systems, there is more liming effect present at the surface of the soil compared to the conventional tillage system where the lime is incorporated in the plough layer (Verhulst *et al.,* 2010). Contrary, Roldan *et al.,* (2007) reported a significant acidification of the top 15 cm depth of the soil due to decomposition of accumulated soil organic matter. Verhulst *et al.,* (2010) attributed the low pH to the acidifying effect of the nitrogen and phosphorus fertilizers applied through banding.

A study conducted by Umar *et al.,* (2011) in the Eastern, Southern and Central provinces of Zambia reported significantly high pH in plots that were under CA for five years. The same author, in a later study but the same provinces of Zambia found non-significant differences in soil reaction between the paired conservation and conventional plots (Umar *et al.,* 2011). The effect of CA practices on soil reaction is dependent on the soil management systems (residue retained/use of cover crops and liming) as well as the period of practice. The contradictory results reported by Umar *et al.,* (2011) under Zambia agro conditions provided a basis for further study to investigate the effect of CA on soil reaction after a longer time of practice.

2.8.2 Soil Organic Carbon (SOC) and Total Nitrogen

Conservation Agriculture practices such as regular addition of organic waste and residue, legume crop rotation and use of green manure or cover crops as well as reduced tillage promote soil organic matter accumulation in the soil. The crop residues that are added to the soil are precursor to the SOC pool. The retention of more crop residues in the soil has been associated with an increase in SOC concentration (Dolan *et al.*, 2006; Wilhelm et al., 2004). A study by Bianco-Canqui and Lal (2007) revealed a correlation between the amount of residue added and SOC. This finding was based on a long-term (10 years) trial of three levels (0, 8, and 16 Mg ha^{-1} on a dry matter basis) on wheat straw applied annually under zero tillage. In the 0-50 cm soil depth, the overall SOC content was 82.5 Mg ha^{-1} in an unmulched soil but 94.1 Mg ha^{-1} with 8 Mg ha^{-1} mulch, and 104.9 Mg ha^{-1} with 16 Mg ha^{-1} mulch. Diekow *et al.*, (2005) also demonstrated that the cereal and legume based cropping systems increased SOC and N contents in the long term (17 years) under reduced tillage experiment in an Acrisol from Southern Brazil. The increase in SOC and N contents was attributed to increased biomass production by the cereals and legumes. (Nijsingh, 2007) also reported increased carbon content in the 0-5 cm layer of reduced tillage fields compared with conventional fields in a research that focused on the effects of reduced tillage on soil organic carbon content in Parana Brazil.

On the hand, Umar *et al.*, (2012) reported contrasting results. Non-significant differences in SOC content were found between the conservation and conventional plots after five years of CA. reasons put forward were that the core principles of CA with regard to the use of cover crops/residue retention were not followed and five year period of practice was not enough for the changes to take effect. The mechanism of capturing C in stable and long term forms depends not only on the amount retained, but also on soil characteristic as well as the composition of the residue (Verhulst *et al.*, 2010). For example, the legume-based rotations contain greater amounts of aromatic C content (a highly biologically resistant form of carbon) than biomass from cereals such as maize. The soluble fraction decomposes faster, unlike lignin which is resistant to rapid microbial decomposition. This observation explains why the legume-based rotation results in a higher SOC turnover. (Verhulst *et al.*, 2010) further explains this to be due to

less incorporation of the organic matter into the soil in reduced tillage, so there is less oxidation of carbon. Soil organic carbon accumulation under CA systems is dependent on a number of factors such as residue retention/use of cover crops, legume crop rotation and reduced tillage; therefore, the rate of accumulation may differ from one region to the other.

2.9 Influence of CA on selected physical properties

2.9.1 Soil Bulk Density and Total Porosity

Bulk density and porosity are some of the important indicators of soil quality. However, these indicators are influenced by farming methods that alter soil physical properties (Rasaily, 2012). The effect of tillage and residue management on soil bulk density is mainly confined to the topsoil (plough layer) than the deeper soil layers which generally exhibit similar densities either under reduced and conventional tillage (Verhulst *et al.*, 2010). A field experiment by Li *et al.* (2007) in northern China demonstrated the long-term effects of zero tillage with residue retention and conventional tillage without residue retention on the soil. This experiment showed the evolution of soil bulk density under the different tillage systems. The first six years showed significant lower values for soil bulk density in the conventional treatment in the first 20 cm depth than the zero tillage. The high bulk density in the zero tillage treatments was attributed to lack of regular soil loosening (Li *et al.*, 2007). However, results obtained in the 5 years that followed indicated similar values of soil bulk density for the two treatments of zero tillage with residue retention and conventional tillage without residue retention. While in the last 2 years of the experiment, bulk density was slightly less in the zero tillage trials with residue retention treatment than in the conventional tillage. The improvement in soil condition was attributed to improved soil structure as a result of increased organic carbon and increased biotic activity in the soil (Li *et al.*, 2007).

2.10 Agricultural Production Simulation Model (APSIM)

Agricultural Production Simulation Model (APSIM) simulates the dynamics of crop growth, soil water, and Nitrogen and soil carbon in a farming system (McCown *et al.*,

1996). It operates on daily time steps and when driven by long term or current daily weather data, can be used to predict the impact of seasonally variable rainfall, both amounts and distribution, on the climate-induced risk associated with a range of crop, water and soil management strategies. APSIM can simulate the impacts of such contrasting management options on a range of crops including maize (*Zea mays. L*), sorghum (*Sorghum bicholor*), pearl millet (*Pennisetum americanum*), chickpea (*Cicer arietinum),* pigeon pea (*Cajanus cajan*), soyabean (*Glycine max*), groundnut (*Arachis hypogea)* and sunflower (*Helianthus annuus).* When properly calibrated for these crops, APSIM can provide an accurate simulation of actual crop yields across a range of soil types and seasons (Dimes, 2005).

APSIM has been used in the tropics of sub-Saharan Africa by various researchers to model fertilizer responses (Shamudzarira and Robertson, 2002), interactions between previous leguminous crop and maize responses to N (Robertson *et al.*, 2005) and crop–weed interactions (Chikowo *et al.*, 2008; Grenz *et al.*, 2006).

According to Robertson *et al.,* (2005) APSIM model is preferred because it can handle more modules relevant for simulating current and future climate change. The model has been applied in Zimbabwe and Kenya to simulate long-term yields. In Zimbabwe, simulation of 46 years of daily climatic data found that farmers' recommendation of using 17 kg N ha^{-1} on annual basis was more appropriate compared to agricultural extension system recommended rate of 52 kg N ha^{-1}, with exception of very bad years (Robertson *et al.*, 2005). In Kenya, the study found that climate variability has significant effect on yield especially for rainfall below 200 mm.

The suitability of APSIM in simulating crops in smallholder farming systems in SAT Africa has been tested over several years and in a number of regions. Building on the precursor simulation work of Keating *et al.*, (1991) in Kenya, the APSIM model has been tested and used, for example in the analyses of fertilizer recommendations for dry and variable environments (Dimes et al., 1999; Shamudzarira *et al.*, 1999); in evaluating crop improvement technologies and their impact on water use efficiency (Okwach *et al.*,1999; Dimes and Malherbe, 2006; Ncube *et al.*, 2008); in assessing the benefits of

improving manure quality and combination with inorganic fertilizer (Carberry *et al.*, 1999; Delve and Probert, 2004; Ncube *et al.*, 2007), in evaluating whole farm productivity and trade-offs between investment in labour and fertilizer (Carberry *et al.*, 2004), extrapolation of research findings to other sites (Rose and Adiku, 1999) and in adding value to seasonal climatic forecasting. It is emphasized that useful outputs from APSIM rely upon reliable long term climatic data, soil description data and experimental data sets to evaluate and validate the model.

Literature has shown that there is very little work that has being done in simulation of CA long term trials in Southern Africa apart from CIMMYT in Zimbabwe. Figure 5 below shows the APSIM simulation framework with induvial crop and soil modules that interface and stimulate the engine in order to output data.

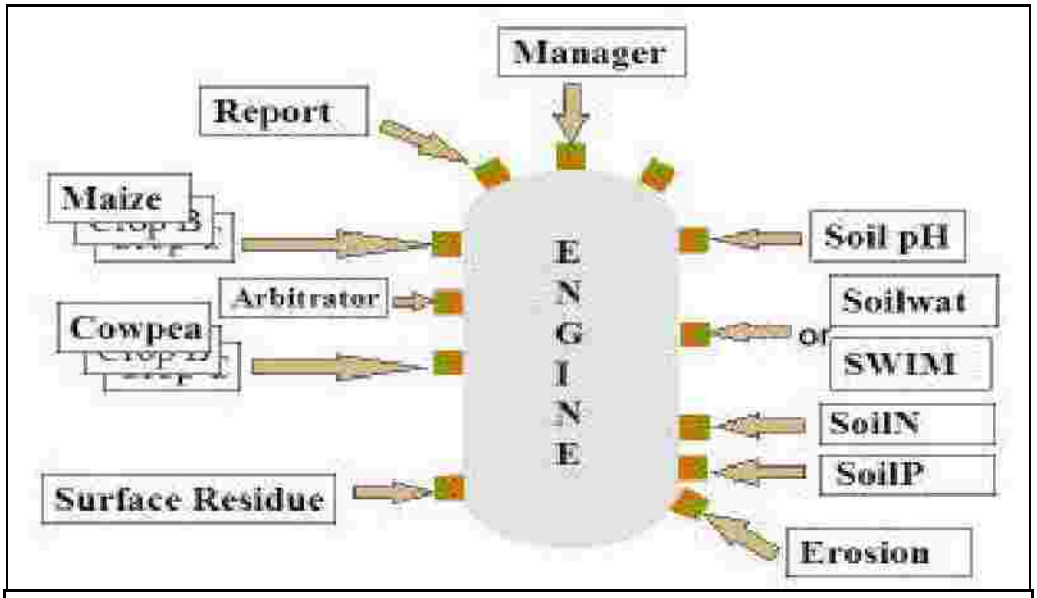

Figure 5: Diagram of the APSIM simulation framework with individual crop and soil

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

This study was conducted at Msekera Research Station which is located about 12 km due West of Chipata town in the Eastern Province. Msekera Research station lies between the Great East Road and Msoro Road. The co-ordinates are Latitude 13^{o} 38.74' S and Longitude 32^{o} 33.51' E and covers an area of about 406 ha at an altitude of 1016 m. The Msekera is drained by a stream perennial which has an earth dam.

Msekera Research Station is located in the Agro-ecological Region II A receiving annual rainfall of about 1092 mm and potential evapotranspiration of 1386 mm. Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants (Reddy, 1986). The rainy season extends from November to April, while the dry cool season extends from May to August. A hot spell with low humidity and high sunshine hours characterizes September and October. The average minimum temperature is 9.5 ^{o} C in the month of June and average maximum temperature is 35.1 ^{o} C in the month of October. The weather shows two distinct periods, the rainy season from November to April, dry season and the coldest from May to September. Temperature and rainfall distribution show that the wet season is cool and the dry season is relatively hot in this Agro-ecological Region II A. Recommended planting dates start at the end of November after the first rain of 25 mm in a single day or 30 mm in two consecutive days in light textured soils, or just before a good rain in heavy textured soils (Reddy, 1986). The rainy season presents 98% of the total annual rains, from November to April, and the dry and cold season with 2% of the rain from April to September. High rainfall variability results in the risky of crop failure under rain fed agriculture; dry spells are likely to happen during the cropping season (Reddy, 1986).

The soil types range from sandy soils which is dominant and covers (163 Ha), to sandy loam clay (53 ha) to clay (36 ha) and sandy clay (11 ha) respectively (Reddy, 1986). The

soil of the study area belongs to the group of fine textured red soils originated from the metamorphic acid rocks (gneiss, migmatite) in situ weathered according to FAO. The predominant soil types at Msekera Research Station are Ferralsols (haplics and rhodics), Haplic Lixisols and Haplic Acrisols (Shitumbanuma, 2008). In the experimental plots, the soil types are Haplic Lixisols, according to FAO soil classification system, with a sandy loam surface soil texture, the slope is generally 1-2% (Wijnhoud, 1997). The soils on the experimental site present good physical characteristics; low fertility especially for Nitrogen and they are moderately acidity with a range between 4.5 to 5.5 pH. Therefore, a good crop yield under rain fed agriculture can be granted with liming and fertilizer application, especially nitrogen and phosphorus (Wijnhoud, 1997).

3.2 Experimental Design

The experimental design used was a split plot with CA and CT treatments as main plot factor. The main plot consisted of CT method that had two treatments namely; mouldboard ploughing on flat (T1) and ridge and furrow (T2) both with sole maize and no crop residue retention. And CA methods that comprised both manual (Basins-T3 and Dibble stick-T4 both with sole maize) and animal traction (Direct seeder with sole maize-T5, Direct seeder maize/cowpea intercrop-T6, Direct seeder maize cowpea rotation-T7, Direct seeder cowpea maize rotation-T8, Direct seeder maize soybeans rotation-T9 and Direct seeder soybeans maize rotation-T10) seeding technologies. The study used two cropping systems under CA namely; rotation and intercrop with residue retention as mulch in both systems. Therefore, the trial comprised of ten treatments per replication and four replications with each plot measured 10 m x 20 m.

3.3 Experimental Treatments

The treatments for the long term trial at Msekera Research station were:-

T1: (CPM 1) Traditional farmers practice using the mouldboard plough on flat, maize as a sole crop, no residue retention, stubble incorporated into the row for the following season

T2: (CPM2) Ridge and furrow system dug by hand, maize as a sole crop, no residue retention, stubble incorporated into the row for the following season

T3: Basin (BA-M), residue retention on the surface, maize as a sole crop

T4: Dibble stick (DIS-M), residue retention on the surface, maize as a sole crop

T5: Direct seeder (DS-M), residue retention on the surface, maize as a sole crop

T6: Direct seeding maize/cowpea intercropping (DS-M/C), residue retention on the surface

T7: Direct seeding maize-cowpea rotation (DS-MC), residue retention on the surface

T8: Direct seeding cowpea-maize rotation (DS-CM), residue retention on the surface

T9: Direct seeding maize-soybean rotation (DS-MS, residue retention on the surface

T10: Direct seeding soybeans-maize rotation (DS-SM), residue retention on surface

3.4 Seeding methods

The cultivars used in this field experiment at Msekera Research Station were MR1 624 for maize, Lukanga for Soybeans and Bubebe for Cowpeas respectively. And for the purpose of this study five treatments were selected and these were;

1. Mouldboard plough on flat (CPM1): traditional tillage treatment was carried out with a mouldboard plough before planting. Land preparation and seeding was done simultaneously in the first week of January. The tillage depth varied in between 10-15 cm and was followed by a hand seeding of sole maize without basal fertilizer application. Maize was seeded at the spacing of 90 cm between rows and 50 cm between planting stations. Basal fertilizer was applied two weeks after seeding and top dressing after 4-7 weeks. Split application of N fertilizer was done to reduce the dose as well as the risk of N leaching during the heavy rains after nitrogen fertilization. The rate of application for basal dressing was 165 kg ha^{-1} and 200 kg ha^{-1} of top dressing. The basal fertilizer application was reduced from the recommended 200 kg ha^{-1} to 165 kg ha^{-1} as a result of site specificity in terms of some essential residual nutrient availability in the soils. The seeding depth was about 10 cm depth. At seeding glyphosate weed control was applied at the rate of 2.5 litres ha^{-1} as a general spray. There was no residue retention under this treatment but were incorporated.

2. Ridge and furrow system (CPM2): traditional tillage treatment was carried out dug by hand by loosening half of soil from the previous ridge and merging it with another

half from the other previous ridge before planting. Land preparation and seeding was done simultaneously in the first week of January. The tillage depth varied in between 15-25 cm and was followed by a hand seeding of sole maize without basal fertilizer application. Maize was seeded at the spacing of 90 cm between rows and 50 cm between planting stations. Basal fertilizer was applied after two weeks and top dressing after 4-7 weeks of seeding. The rate of application for basal was 165 kg ha^{-1} and 200 kg ha^{-1} of top dressing. The seeding depth was about 10 cm depth. At seeding glyphosate weed control was applied at the rate of 2.5 litres ha^{-1} as a general spray. There was no residue retention under this treatment.

3. Basins (BAM): the basins were dug with the use of a hand hoe (Chaka hoe) before seeding. The basins were approximately 20 cm x 30 cm x 15 cm, with spacing of 90 cm between rows and 50 cm between basins in the row; the basins were dug before the starting of the cropping season. Land preparation and seeding was done simultaneously in the first week of January. In the maize crop, spacing was 90 cm between rows and 50 cm between planting stations, aiming at a seed rate of about 44,444 plants ha^{-1}. For cowpea a spacing of 45 cm between rows calibrated to give approximately 20 kg ha^{-1} seed. Also in cowpea intercrop, cowpea seed was planted between the maize rows with one planting station between 2 maize planting stations, 2-3 seeds per station. In soybeans the spacing was 45 cm between rows and approximately 5 cm between plants. Approximately 120 kg ha^{-1}, planting to achieve 444,444 plants/ha. The seed was also inoculated before planting. Top dressing at the rate of 200 kg ha^{-1} was applied as split application in week 4 and 7 after planting in maize and not for cowpea and soybeans. Weed control at seeding was done using an herbicide glyphosate at 2.5 litres ha^{-1}. Weed control after crop emergence in the CA plots was manually done. Crop yield (grain and above ground biomass) were measured. Maize Stover was retained as residue at the rate of 3 ton ha^{-1}.

4. Dibble stick (DIS-M): This seeding method is a no tillage manual traction and uses a sharp pointed stick to make a planting station. Land preparation and seeding was done simultaneously in the first week of January. Residue retention on the surface was at a rate of 3 ton ha^{-1}, maize as a sole crop. In the maize crop, spacing was 90 cm between

rows and 50 cm between planting stations, aiming at a seed rate of about 44,444 plants ha^{-1}. For cowpea in Maize-Cowpea rotation at cowpea phase, a spacing of 45 cm between rows was used calibrated to give approximately 20 kg ha^{-1} seed. Also in cowpea intercrop, cowpea seed was planted between the maize rows with one planting station between 2 maize planting stations, 2-3 seeds per station. For soybeans in Maize-Soybeans rotation at soybeans phase, spacing of 45 cm between rows and approximately 5 cm between plants was applied. Approximately 120 kg ha^{-1}, planting to achieve 444,444 plants/ha. The seed was also inoculated before planting. Top dressing at a rate of 200 kg ha^{-1} urea was applied as split application in week 4 and 7 after planting in maize and not for cowpea and soybeans. Weed control at seeding was done using herbicide glyphosate at 2.5 litres ha^{-1}. Careful and superficial hand hoe weed control after crop emergence in the CA treatments was manually done. Crop yield (grain and above ground biomass) were also measured.

5. Direct Seeding (DSM): a technique that refers to seeding/planting without ploughing or cultivation to prepare a seedbed. Direct seeding with animal traction direct seeder allowed a simultaneous application of basal fertilizer at a depth of 10 cm. The direct seeder was prior calibrated to deliver the required seed and amount of fertilizer. Land preparation was and seeding was done simultaneously in the first week of January. In the maize crop, spacing was 90 cm between rows and 50 cm between planting stations, aiming at a seed rate of about 44,444 plants ha^{-1} with three maize seeds per station thinned to two per station in treatment 1 to 3. Whilst two maize seeds were planted per station in treatment 4 and later thinned to one seed per station. For cowpea a spacing of 45 cm between rows calibrated to give approximately 20 kg ha^{-1} seed. Also in cowpea intercrop, cowpea seed was planted between the maize rows with one planting station between 2 maize planting stations, 2-3 seeds per station. In soybeans the spacing was 45 cm between rows and approximately 5 cm between plants. Approximately 120 kg ha^{-1}, planting to achieve 444,444 plants/ha. The seed was also inoculated before planting. Top dressing at a rate of 200 kg ha^{-1} of urea was applied as split application, 4 and 7 weeks after planting in maize and not for cowpea and soybeans. Weed control at seeding was done using an herbicide glyphosate at 2.5 litres ha^{-1}. Careful hand hoe weed control

after crop emergence in the CA plots with retained residues was manually done. Maize Stover was retained as residue at the rate of 3 ton ha^{-1}.

3.5 Data collection from the field experiment

The study adopted the already established CA long-term trial at Msekera Research Station. The same experimental design was used by the study during the 2014/15 season. Crop data was collected through direct observation and registration of crop phenology stages and crop management. Crop yield (grain and above ground biomass) was measured from the field experiment.

3.5.1 Soil Moisture

Access tubes already installed on the CA long-term trial at Msekera Research Station were used to measure moisture from CPM 1&2, BAM, DISM, DSM, DS-M/C and DS-MC treatments. The study measured up to 60 cm depth with capacitance probes (PR-2 probes, Delta-T Device Ltd, UK) twice per week during the cropping season. Data collected from the 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-60 cm depth was further analyzed in this study. Mean soil moisture in mm for each depth layer was determined for the cropping seasons during 2014/2015 season.

3.5.2 Normalized Differences Vegetation Index (NDVI)

To collect greenness of the crops, the Green Seeker Handheld equipment (Figures 6 A and B below) was used. The study obtained data first at 24 days after planting (DAP). Thereafter, the NDVI readings were collected on weekly interval. NDVI measurements were taken from the central rows of a growing crop in all the treatments and replications used in this study during the 2014/2015 season. The Green Seeker Handheld equipment was used to collect data under this research by simply pressing it at least 30 cm above the leaves of maize, cowpea and soybeans whilst moving along the central row of each treatment and getting instant digital readings.

Theoretically, NDVI is calculated from the reflectance measurements in the red and near infrared (NIR) portion of the spectrum. NDVI provides an estimate of vegetation health and a means of monitoring changes in vegetation over time. The pigment in plant leaves,

chlorophyll, strongly absorbs visible light (from 0.4nm to 0.7nm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7nm to 1.1nm). The more leaves a plant has, the more these wavelengths of light are affected, respectively (Holme *et al.*, 1987). The typical range of NDVI is between -0.1 (NIR less than VIS for not very green area) to 0.6 (for a very green area). In a nutshell, NDVI is a measure of near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The result of this formula is called the Normalized Difference Vegetation Index (NDVI). Written mathematically, the formula is:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \quad (1)$$

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves (Holme *et al.*, 1987). In this study zero NDVI value represents either bare soils or already harvested crop.

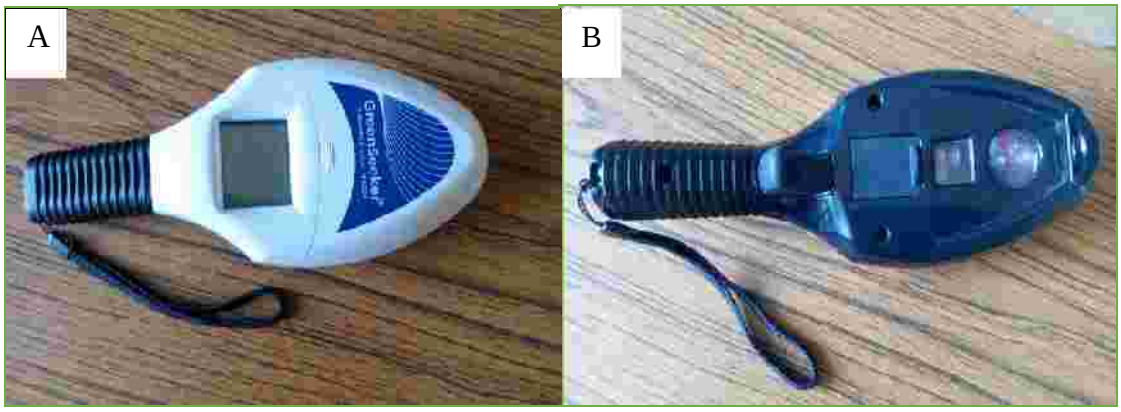

Figure 6: (A and B) GreenSeeker face and back sides

In this study NDVI was used to measure the chlorophyll content in the leaves for photosynthetic activities of the crop in relation to growth and yield of maize (Zeay mays

L.) from vegetative to grain filling stage. The NDVI data was not directly used as inputs for simulation of the APSIM model as it was an only an indicator of both observed biomass and grain yield. The use of NDVI in this study provided a comparative platform for the two systems (CT and CA) throughout the growth period.

3.5.3 Crop Growth and Yield

3.5.3.1 Maize

Five sub plots of (5 meters x 2 rows) were measured out of each plot. Growth and yield parameters were then obtained for each of these sub-plots. And these were; plant count, plant height, ear height, number of cobs, the distance between four rows over the sub-plot, fresh weight of cobs, and the fresh weight of biomass. Then a sub-sample of 10 cobs that is 2 cobs from each sub-plot was collected and the fresh weight obtained. A maize stalk sample (biomass) was also obtained from the plot ranging between 500 g to 1000 g. Finally the dry weight was obtained in order to extrapolate the fresh weights obtained at harvest.

3.5.3.2 Cowpea

Five sub-plots of (5 m x 4 rows) were measured out of each plot containing Cowpeas. Growth and yield parameters were then obtained for each sub-plot. The parameters measured were plant count, fresh weight of biomass and the fresh weights of all fertile pods. Also a sub sample of the pods was then obtained and weighed immediately and later used to determine the fresh and dry weights. A stalk sample (biomass) was also obtained and weighed immediately as well as after drying. Distance between six rows was also obtained to determine the actual area harvested. Finally the dry weights were obtained in order to extrapolate the fresh weights obtained at harvest.

3.5.3.3 Soybeans

Five sub plots of (5 m x 4 rows) were measured out of each plot containing Soybeans. Growth and yield parameters were then obtained for each sub-plot. The parameters measured were plant count, pods per plant, plant height, pod clearance, fresh weight of biomass including all fertile pods. A sub-sample of the pods was then obtained and weighed immediately and later to determine the fresh and dry weights. A stalk sample

(biomass) was also obtained and weighed immediately as well as after drying. Distance between six rows was also obtained. Finally the dry weights were obtained in order to extrapolate the fresh weights obtained at harvest.

3.5.4 Biomass Yield

The harvest area was identified and before each plant was harvested, the plant height was measured. The plant was cut off at as close to ground level as possible, any brace roots removed, and the plant cut into segments and placed in a bag. All dead leaves still attached to the plant were placed in the bag as well. The plant material were placed in a control temperature ovens in the laboratory to quickly as possible facilitate the gradual drying. Once all samples were taken, they were moved to an air conditioned laboratory for dissection and measurement.

3.6 Agricultural Production Simulation Model (APSIM)

3.6.1 Model Calibration

Model calibration and validation against an independent data set was an essential step in model setup. APSIM model was parameterized and evaluated for maize grain, biomass yields and soil water under rainfall and temperature climate change scenarios. In this study APSIM model was evaluated for simulation of maize grain and biomass yield and soil water parameters. The inputs used for the evaluation of model simulation included; days after sowing, crop phenology, soil N, weather, and crop management information as these were the major constituent of optimal crop productivity. The soil chemical and physical properties input data used for calibration was sourced from *(Mwaanga, 2015 Unpublished)* who conducted a similar study on the same CA long term trial the previous year (Table 1). Genotypic coefficients were incorporated into maize in file of model until observed and simulated results were close to each other.

Table 1: Soil chemical and physical properties input data used for calibration of the APSIM model at Msekera Research Station experimental site.

Soil depth (cm) (mg/kg)	pH ($CaCl_2$)	SOC (%)	BD (g/cm^3)	Total N (%)	P
0-10	4.35	1.191	1.56	0.08	11.6
10-20	4.47	0.978	1.6	0.09	11.0
20-30	4.53	0.652	1.63	0.11	11.0
30-40	4.53	0.614	1.69	0.12	7.4
40-60	4.8	0.59	1.70	0.12	6.9
60-80	4.8	0.46	1.73	0.l2	5.2

During the long term crop simulation calibration Sc 501 cultivar from the model crop file for maize was selected representing medium to late maturity similar to MRI 624 used at Msekera Research Station experimental site. On the other hand, Banjo cultivar was used for cowpea with similar characteristics to Bubebe seed. Also Magoye cultivar was used for soybeans with similar characteristics to Lukanga seed.

Table 2: The APSIM data inputs used for the calibration of the model with *curve numbers (CN) 70 for Conservation Agriculture and 85 for Conventional Tillage at Msekera Research Station experimental site

Depth (cm)	Lower Limit (%)	DUL (%)	SAT (%)
0-10	5	15	27
10-20	7.9	16	31
20-30	8.6	19	33
30-40	13	23	33
40-60	17.7	24	34
60-100	18	24	36

** Since APSIM model maintained a daily balance of both crop and residue cover for both CA and CT systems.* ***Curve number (CN)*** *was a dynamic parameter that changed on a daily basis during the simulation.*

The main parameters used in this calibrating were SAT (Saturated soil water content), DUL (Drained upper limit of soil water content) and LL15 (Lower limit of soil water content) as shown in Table 2. LL15 is the Bar lower limit of soil water content (Jones and Kiniry, 1986). It was approximately the driest water content achievable by plant extraction. This defined the "bottom of the bucket". DUL is the drained upper limit of soil water content. It was the content of water retained after gravitational flow (Jones and Kiniry, 1986). DUL is sometimes referred to as "Field Capacity". SAT is the saturated water content. This defines the "top of the bucket" or volumetric soil water. Several methods are commonly used to determine these parameters. SAT was equivalent to total porosity of the soil calculated from the soil bulk density. Bulk density was a mandatory parameter for this APSIM model, and so it is collected as secondary data requirement from the CA long term trials. DUL and LL15 were determined in the experimental field. DUL was determined through measurement of soil water content after an extended period of drainage following saturation. And LL was determined after maximal drawdown of soil water content by plants (Dalgliesh and Foale, 1998). Alternatively, DUL and LL15 can also be estimated from laboratory measurements of soil water content at 100 and 15,000 cm matric suctions, respectively (Gardner, 1988).

Therefore, apart from model simulations SAT, DUL, and LL15 can also be estimated from regular observations of soil water content, including periods of wetting up and drainage, and periods of drying down by plants (Dalgliesh and Foale, 1998). Soil water content often varies between SAT and DUL during periods of frequent rewetting and decrease to LL15 during periods of high crop water use and minimal water input. Since the CA long-term data on soil water variation was available, rapid estimates of soil hydraulic properties was obtained from direct interpretation of soil behavior from the experimental plots.

3.6.2 Model Evaluation

The model was validated using the data collected by the study from CA long-term field experiment during 2014/2015 season. The main focus of this study was to simulate maize grain yield, biomass production and soil water content using rainfall and temperature climate change scenarios. To compare simulated with observed data under 2014/15 season. The performance of the APSIM model was assessed through a validation skill scores using Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE) and Modeling Efficiency (ME).

Statistically the RMSE of a model prediction with respect to the estimated variable P_i is defined as the square root of the mean squared error:

$$Root\ Mean\ Square\ Error\ (RMSE) = \left[\frac{1}{n}\sum_{i=1}^{n}\left(P_i - O_i\right)^2\right]^{0.5} \quad \text{..... (2)}$$

$$Modelling\ Efficiency\ (ME) = \frac{\left[\sum_{i=1}^{n}\left(O_i - O_m\right)^2 - \sum_{i=1}^{n}\left(P_i - O_i\right)^2\right]}{\sum_{i=1}^{n}\left(P_i - O_i\right)^2} \quad \text{.....(3)}$$

$$Coefficient\ of\ \text{Re}sidual\ Mass\ (CRM) = \frac{\sum_{i=1}^{n}O_i - \sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i} \quad \text{..... (4)}$$

$$Normalized\ Root\ Mean\ Square\ Error\ (NRMSE) = \frac{\text{RMSE}}{\text{O}_\text{m}} x100\% \quad \text{..... (5)}$$

Where P_i is simulated values; O_i is measured values; O_m is mean of measured values, and n is number of the observations. The Root Mean Square Error (RMSE) is a measure of precision. The Modeling Efficiency (ME) also referred to as the coefficient of Nash-Sutcliffe (Mahdian and Gallichand, 1995) is a measure of degree of fit between simulated and measured data. It is similar to coefficient of determination (R^2). ME varies

from negative infinity (-8) for total lack of fit to 1 for an exact fitting (Mahdian and Gallichand, 1995). The Coefficient of Residual Mass (CRM) is an indicator of the tendency of the model to either over- or under- predict measured values. A positive value of CRM indicates a tendency of underestimation, while a negative value indicates a tendency of overestimation (Antonopoulos, 1997).

Statistically, the goodness of fit was assessed by calculating the RMSE and the NRMSE. These indices provided a measure of the absolute and the relative error, respectively, between observed and simulated values (model fit improved as both indices approach zero). The ME and the R^2 were also computed to provide a measure of the predictive ability of the model (the higher the value the better). Among the above indices, the RMSE and the NRMSE are preferred for model comparison. Ma et al., (2011) stated that for a "point" agricultural model like APSIM to be calibrated adequately the R^2 and the ME should be above 0.7 and 0.8 respectively. While, the performance of the model was very good if the NRMSE <10%, good if NRMSE ˜ 15%, and satisfactory if NRMSE ˜ 20%.

3.6.3 Simulation of long term effects of CA practices on grain yield and soil water dynamics

The calibrated and validated APSIM model was used to simulate the CA long term climate change scenarios based on four treatments tested in the field experiment. The treatments used for crop simulation were Conventional Tillage (CT) also referred to as Farmer Check, Basins, Dibble Stick and Direct Seeder. During calibration crop residues were not retained on the farmer check treatment. However, 37.5 % crop residues were retained on the soil surface in the model for the rest of the CA treatments during calibration. Msekera Research Station currently does not have digitalized soil and weather data. Therefore, the study suggested to use simulation data calibration input for soil and weather from Chitedze Research Station in Malawi. Chitedze Research Station was preferred as a result of its proximity to the experimental site and similarities in soil and weather conditions. Simulation outputs for maize grain yields and soil moisture content were plotted for the four treatments to give a trend on crop productivity and soil water for the period of 85 years (2015-2099).

3.7 Statistical Analysis

Analysis of variance (ANOVA) is a statistical method in which the variation in a set of observations is divided into distinct components. Comparison of treatments effects for observed data on NDVI, maize grain, biomass yields and soil water were analyzed using ANOVA. Also mean separation was determined by standard error of difference method using GenStat version 17. Furthermore, linear regression (R^2) was used to compare results between the observed and simulated for biomass and grain yield and soil water.

CHAPTER FOUR

4.0 RESULTS AND DICSUSSIONS

4.1 Results

4.1.1 Effect of conventional and CA practices on NDVI

The NDVI results showed variations between the CT and CA treatments and days after planting (DAP). CT treatments had lower (P<0.001) NDVI values in the initial period compared to CA treatments with residue retention on the surface and with rotation treatment (Table 3). This table only shows that there were significant differences in treatment, Days after Planting (DAP) and interaction on NDVI, biomass and grain yield. Sole maize planted in CT plots had poor influence on crop development with early lower NDVI values compared to CA practices (Figure 7). CA treatment with Dibble Stick Maize-Cowpea (DS-MC) rotation at maize phase treatment had higher (P<0.001) NDVI on average at early crop development as generated by the ANOVA (Table 3). There was significant difference (P<0.001) between CT and CA treatments later in the season. CT treatment with mouldboard plough (CPM 1) had lower (P<0.001) NDVI values compared to all other treatments (Table 3). However, were the NDVI values were zero meant that the crop was either at seeding or harvest stage during the time of obtaining the readings.

Table 3: Summary of Analysis of Variance (ANOVA) means of squares for measured NDVI, biomass and maize grain yields

Sources of Variance	Degree of freedom	NDVI	Biomass yield	Maize grain yield
Replication	3	0.004040^{NS}	4479758***	3202689***
Treatment	7	0.274388***	1142382**	1836726***
Days after Planting	6	0.548922***		
Treatment x DAP	56	0.074513***		

^{Ns} *Not significant, ***Significant at 1% probability level, **Significant at 5% probability level*

NDVI line graph results for ten treatments both for CT and CA treatments were represented in Figure 7. Results revealed that CT treatment (T1) had the lowest NDVI value initially compared to CA practice (T4) which had the highest value (Figure 7). There was a significant difference observed at every interval of NDVI readings between CT and CA treatments. Statistically, this is supported in Table 3 were there is significant difference between NDVI and treatment at 1% probability level. The NDVI values for all the treatments dropped at 60 DAP as this is attributed to the prolonged dry spell experienced at Msekera Research Station. The results revealed that T7 treatments had higher NDVI values at 80 DAP and later started declining (Figure 7).

Figure 7: Observed Normalized Difference Vegetation Index (NDVI) based on crop growth development between conventional tillage and CA practices at Msekera Research Station

Furthermore, result revealed NDVI results highly significantly different among the eight treatments after days of planting (Figure 7). Statistically, (Table 3) for NDVI revealed highly significant difference ($P<0.001$) among the seven intervals of DAP.

4.1.2 Effect of conventional and CA practices on maize biomass and grain yield

CT treatments were compared with CA treatments in terms of biomass yield that was tested at 95% confidence level with 24.05% coefficient of variation, 620.8 Standard Error and with $P<0.025$ across treatments as generated by the ANOVA (Table 3) for biomass yield. There were variations observed in terms of biomass yield among treatments. Ridge and furrow system (CPM2) had lower ($P<0.025$) biomass yield compared with Direct Seeder with maize and soybean rotation at maize phase (DS-MS) that had the highest biomass yield (Figure 8). In addition, there were highly significant difference in maize biomass yield between CT treatment (CMP2) and CA treatment (DS-MS) as shown in Figure 8. Furthermore, there were no significant difference between the two CT treatments (CMP1 and CMP2). However, there was significant difference among the six CA practiced treatments with more prominence between DS-M/C and DS-MS respectively.

Figure 8: Biomass yield measured from the long term CA trials at Msekera Research Station during 2014/15 season

Similarly, the same systems were used to compare maize grain yield tested at 95% confidence level with 23% coefficient of variation and 632.8 Standard Error. There was

significant differences (P< 0.003) within treatments for measured maize grain yield as generated by the ANOVA in Table 3. CT treatments with mouldboard plough on flat (CPM 1) had the lowest maize grain yield as compared with Direct Seeder with maize and cowpea rotation at maize phase that had the highest maize grain yield (Figure 9). There was a significant difference of 1802 Kg ha^{-1} on observed grain yield compared between Conventional Tillage (CPM2) ridge and furrow and Conservation Agriculture (DS-MC) treatments.

Furthermore, maize grain yield also generated highly significant difference (P<0.003) among treatments (Table 3). This statistical analysis from the ANOVA was confirmed this variation and is graphically shown in Figure 9. In addition, there was highly significant difference (P<0.003) between CT treatment (CPM1) and CA treatments (DS-MS) were the later had higher maize grain yield (Figure 10). Also results revealed significant difference (P<0.003) among the CA treatment with DS-MC having a higher maize yield than DS-M/C (Figure 9).

Figure 9: Maize grain yield measured from the long term trial at Msekera Research Station during 2014/15 season

4.1.3 Evaluation of the long-term effects of rainfall and temperature changes on crop yields under CA predicted using APSIM

APSIM long term simulated and observed outputs for maize biomass yield for CT treatments was compared with CA treatments using linear regression R-squared (Figure 10). R-squared provides an estimate of the strength of the relationship between the observed and simulated values of the model. R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. The R-squared obtained accounts for 39.4% that was low. This meant that there was less variance that was accounted for by the regression model and the far apart the data points fall to the fitted regression line (Figure 10). Furthermore, the magnitude of the differences ($p<0.001$) between observed and simulated results is generated in the ANOVA table (appendix 7). The simulated resulted had higher average biomass yields compared with the observed results that had lower results. Within the simulated measurement, conventional ploughing treatment had higher biomass yield compared to basins treatment with lower biomass yield (Figure 10). However, there was no significant difference ($p<0.076$) within treatments on biomass yield for the observed experimental results as generated by ANOVA table (Appendix 7). However, the model over-predicted the observed biomass yield for the four treatments compared to the measured results as confirmed by low R-squared (Figure 10).

Figure 10: Comparison between the observed and simulated biomass yield from both conventional tillage and CA practices for 2014/15 growing season at Msekera Research Station

On the other hand, the comparison between observed and simulated results on maize grain yield showed a positive correlation (Figure 11). The regression model below (Figure 11) accounts for 74.8% of the variance. There was more variance that was accounted for by the regression model and the closer the data points felled to the fitted regression line. The generated ANOVA on maize grain yield (Appendix 8) confirmed this variation. There was significant differences ($p<0.001$) between average observed and simulated measurements (Appendix 8). There was significant differences ($p<0.031$) among the observed results for maize grain yield as generated by the ANOVA table (Appendix 8).

Figure 11: Comparison between observed and simulated maize grain yield from both conventional tillage and CA practices for 2014/15 growing season at Msekera Research Station

The baseline weather data used for the long-term simulation comprised of the following climate change scenarios namely; Baseline-Default no climate change (Figure 12), 11.3% increase in rainfall (Figure 13), 11.3% decrease in rainfall (Figure 14), 1 ^{o}C increase in temperature (Figure 15), 2 ^{o}C increase in temperature (Figure 16) and 3 ^{o}C increase in temperature (Figure 17) respectively.

Figure 12: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with baseline no climate change scenarios application at Msekera Research Station

Figure 13 shows the graphical APSIM simulated output results for maize grain yield for 85 seasons. Increase in rainfall by 11.3% per annum applied to the APSIM model CA long term simulation increased maize yield for CA treatments by 0.4% compared with the baseline no climate change scenario.

Figure 13: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with 11.3% rainfall increment as climate change scenario at Msekera Research Station

When rainfall was reduced by 11.3% per annum (CC2-11.3% rainfall decrease) there was an incraese in simulated average maize grain yield for CA treatments (Figure 14). Therefore, simulated avearge maize grain yield for CA treatments incresased by 4% compared with baseline-no climate change scenario. Moreover, maize grain yield outputs for CA treatments varied among different seasons used in the APSIM model simulation for 85 seasons.

Figure 14: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with 11.3% rainfall decrease as climate change scenario at Msekera Research Station

The simulated results revealed that temperature variability had a negative effect on maize grain yield for CT treatment. When temperature increase of 1 ^{o}C was applied to the crop simulation model as a climate change scenario, the average maize grain yield decreased for CT treatment (Figure 15). Simulated average maize grain yield for CT treatment decreased by 11% (454 Kg ha^{-1}) compared with the baseline-no climate change scenario application to the model (Figure 15). Furthermore, the increase in temperature resulted into 22 seasons experiencing adverse drought out of the total 85 seasons simulated by the APSIM model.

Figure 15: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with 1^{o}C temperature increment as climate change scenario at Msekera Research Station

Similarly, when tempearature was increased by 2 ^{o}C as climate change scenario (CC4-2 degree increase) the simulated average grain yield for CT treatment continued to decrease (Figure 16). The simulated output results showed a negative effect of temperature rise on maize grain yield for CT treatment. There was a 21 % (868 Kg ha^{-1}) reduction in maize grain yield compared with the baseline-no climate change simulation (Figure 16).

Figure 16: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with $2^{o}C$ temperature increment as climate change scenario at Msekera Research Station

When temperature of 3 ^{o}C increase was applied as climate change scenario (CC5-3 degree increase) to the crop simulation model, a further negative effect on maize grain yield for CT treatment (Figure 17). As a result of temperature rise by 3 ^{o}C, the APSIM model predicted an average maize grain yield reduction of 31% (1278 Kg ha^{-1}) for CT treatments compared with the baseline-no climate change scenario output results. In addition, application of (CC5-3 degree increase) as climate change scenario in this crop simulation model further revealed that apart from the maize grain yield reduction for CT treatment, 28 seasons will experience adverse drought that will complement reduction in yields (Figure 17).

Figure 17: Predicted maize grain yield from conventional tillage and CA practices using APSIM simulation for 85 growing seasons long-term trial with $3^{o}C$ temperature increment as climate change scenario at Msekera Research Station

4.1.4 Evaluation of the long-term effects of rainfall and temperature changes on soil water under CA predicted using APSIM

The comparison between the observed and simulated data using a linear regression (R^2) on soil water is shown in Figure 18. The regression model accounts for 91.40% of the variance, which was a high value. The graphical linear regression analysis revealed that the more variance that was accounted for by the regression model the closer the data points fall to the fitted regression line. Theoretically, if a model could explain 100% of the variance, the fitted values would always equal the observed values and, therefore, all the data points would fall on the fitted regression line. The R-squared value in this case was higher and closer to 100%, and this explained that the model was perfectly calibrated (Figure 18).

The average values for accumulated soil water from the different soil layers were 73.29mm for observed and 70.95mm for the simulated results respectively. Whilst, the average RMSE was 5.57 and NRMSE was 8.6% confirming that the model perfectly predicted the long term effects of rainfall and temperature changes on soil water accumulation for the four treatments.

Figure 18: Comparison between observed and simulated soil water from both conventional tillage and CA practices for 2014/15 growing season at Msekera Research Station

The baseline weather data used for the long-term soil water simulation comprised of the following climate change scenarios namely; Baseline-Default-no Climate change (CB), 11.3% increase in rainfall (CC1), 11.3% decrease in rainfall (CC2), 1 oC increase in temperature (CC3), 2 oC increase in temperature (CC4) and 3 oC increase in temperature (CC5) respectively.

4.2 Discussions

4.2.1 Effect of conventional and CA practices on Normalized Difference Vegetation Index (NDVI)

The application of NDVI that combined the readings at different wavelengths provided a more precise determination of the plant nutritional status for maize crop. NDVI showed nitrogen content in the leaves through chlorophyll at various phenological stages in this case of maize crop that was grown under different treatments at Msekera Research Station. In this study, results revealed CA treatments had higher NDVI values at the initial stage of growth compared with CT treatments. This was attributed to the availability of soil N the maize crop was getting under CA practice through N

mineralization process in addition to the applied inorganic N. It was further clear that the two CT treatments had lower initial NDVI readings as compared to the CA treatments. This was attributed to the absence of additional soil N from residue retention apart from the synthetic N uptake by the maize crop. It is important to note that nitrogen is primarily introduced to the soil either through synthetic fertilizer, or the breaking down of crop residue and soil organic matter. Previous work has shown that NDVI values were most closely correlated with the nitrogen content of the leaves (Raun et al. 2001). Therefore, it was observed that the absence of crop residue in the CT treatments contributed to unavailability of soil N from the breakdown of crop residue.

The study suggested that nitrogen nutrition in soils especially in CA treatments had significant effects on plant growth and photosynthetic characteristics of the leaves of maize crop. Increasing soil N availability through decomposition of crop residues in CA treatments resulted in greater biomass production at the initial stage of plant growth. And according to Riley (1998) who reported that availability of nutrients is normally greater when they are associated with organic matter through retention of crop residues. Riley (1998) further reported that soil chemical fertility can be enhanced by applying manure, fertilizer, compost and lime. He added that crop residues and soil organic matter (SOM) are broken down by soil organisms and with time, the nitrogen from the organic material is made available to the crop. In addition, Riley (1998) noted that in CT treatments this process was very fast and excessive so fast that SOM levels were reduced and the soil degraded. However, Riley (1998) emphasized that with no tillage in CA treatments, the lower mineralization and breakdown provides nitrogen (and other nutrients) for crops but the availability is slower and more even.

NDVI is a proven tool that has the potential to assess N through chlorophyll content at leaf, plant, field, regional and global scales and that was used in this study. The presence of nitrogen in the leaf of maize crop from both soil and inorganic N for all the treatments gave it its initial green colour. The more N in the leaf of maize crop the higher the NDVI value detected by the hand held GreenSeeker Optical Sensor Unit that was used in the study. Therefore, the higher the NDVI value the more greener the plant and more chlorophyll and photosynthetic activities in the leaves of the plant. Generally, CA

treatments had higher NDVI values that translated into maize leaves with greener phenological appearances at the initial 24 days after planting (DAP). The same greenness of the leaves prevailed in the CA treatments up to 60 DAP despite the experienced prolonged dry spell at Msekera Research Station. The greenness of leaves for maize crop was attributed to availability of N from both SOM and inorganic supplemented fertilizer in the CA treatments. And also the residue on the soil surface increased water infiltration and storage that was cardinal requirement for plant growth. After 60 days of planting, the supply of N to the leaf of maize crop was reduced and concentrated on grain filling of the cobs. At that time of maize crop grain filling, the chlorophyll content in the leaves started to decrease due to translocation of assimilates from leaf to grain that led to the conversion of the lower color of leaves to yellow most predominately in the CT treatments. From the phenological observation, the greenness of the leaves changed to pale green colour and the lower leaves eventually started yellowing. At that stage of plant growth, the NDVI values started going down for all the treatments more especially the CT treatments.

However, the results also revealed highly significant differences within CT treatments that recorded lower NDVI values. Furthermore, there was highly significant difference in NDVI values within treatments in terms of days after planting (DAP). When analyzed through time or days after planting, the NDVI readings revealed that vegetation was thriving under CA treatments with higher NDVI values as compared to CT treatments with lower NDVI values most especially during the dry spell period. Poor soil moisture storage was detected in the CT treatments through observed crop stress signs caused by too much evaporation as a result of high soil temperature. This was as a result of the absence of crop residue on the soil surface. The condition was exhibited throughout the periodic NDVI measurements on the experimental plots. Collectively, the results suggested that increased growth of maize crop at high sunlight and optimal nitrogen nutrition was related to greater capacity for photosynthesis and translocation in mature leaves, and this gave the greenness that was detected through NDVI readings.

NDVI values were able to show the maize crop growth at several stages, it was also observed that under CT treatments the nitrogen supply to the plant was not adequate.

This was because ploughing and hoe ridging under CT treatments disturbed soil layers and thereby destroying the structure of soil. When the soil structure was destroyed, water infiltration and soil organic matter was also reduced. Also absence of organic matter under CT treatments rendered soil less capable of retaining sufficient nutrients and water in the soil. The opposite was observed in the CA treatments were the presence of SOM lasted longer in the soil as humus. And according to Thierfelder and Wall (2014) plant nutrients associated with humus are more available than inorganic forms of the same nutrients. This confirmed the higher NDVI values and the greener maize leaves obtained from the CA treatments as compared with the CT treatments.

4.2.2 Effect of conventional and CA practices on maize yield

Biomass yield under CT treatments (Figure 8) showed significant difference between the two CT treatments used in this study at Msekera Research Station during the 2014/15 season. CPM1 had higher biomass yield compared with CPM2 under the same technology as can be seen in Figure 8. The higher biomass yield recorded in the CPM 1 treatment under CT treatment was attributed to the availability of applied inorganic nutrients to maize crop. CPM1 treatment had high soil water accumulation as measured using the capacitance probes and this contributed to higher biomass yield. Therefore, the results suggested that there was less runoff of water and nutrients applied through basal dressing fertilizer observed in CPM1 compared with CPM2.The CPM 1 treatment was able to utilize nitrogen in the initial stage of maize crop growth that was translated to the stem and leaves for photosynthetic process. The results further speculate that the sole maize grown under CPM1 treatment had sufficient nitrogen available for uptake during plant growth and that resulted in higher biomass yield. This was confirmed through the higher NDVI values measured under CPM1 compared CPM2 at initial plant growth stage (Figure 7).

On the other hand, there was a highly significant difference between the biomass yield from CT and CA treatments (Figure 9). Direct seeder maize-soybeans (CA) treatment had higher biomass compared with conventional practice ridge and furrow (CT) treatment that had lower biomass yield. This was attributed to the presence of crop residue on the surface of the soil for CA treatment during the growth. Crop residue

retained on the surface of the soil improved the soil structure and nutrient availability through decomposition. This was beneficial to the growth of maize crop under CA treatment that culminated into higher biomass yield. Phenological assessments of germination on CA treatments showed an earlier and more even germination compared to CT treatments, contributing to the biomass yield advantages. In addition, crop residues were retained in CA treatments, whereas they were removed from CT treatments in line with the current farmer practices in Zambia. The field observation further revealed that CA treatments generally worked well with residues retention, as many benefits were derived from surface mulch.

However, the drawback from the on-farm fields for most smallholder farmers is that they manage mixed crop-livestock systems and depend on the residues for fodder during the dry season. And according to similar findings by Thierfelder *et al.,* (2014), who observed that residues retained on the surface of the soil increased infiltration, more of the rainfall went into the soil and less was lost by evaporation. So there was enough water in the soil for plant growth. Some water may have been lost to the crop by drainage, but in most cases especially during the prolonged dry spell periods experienced during the study, there was sufficient water available for plant growth. Thierfelder *et al.,* (2014), further confirmed that crop residues protect against soil erosion because more water goes into the soil (increased infiltration), less water runs off the land. Therefore, the study suggested that residues retained on the soil surface slowed the flow of runoff water across the land. The combination of these two factors leads to large reductions in water erosion. Mupangwa *et al.*, (2012), further reported that residues also protected the soil from the wind, and as the soil was not loosened by tillage in CA systems, there was markedly less wind erosion. The field observations further revealed that crop residues increased biological activity. The other observation was that residues provided a constant food source for soil fauna and flora, and a habitat for many organisms. Therefore, it was obvious that the populations of soil organisms increased under CA. Most of these soil organisms were beneficial to plant growth as they assisted to produce soil pores or attacked crop pests found in the CA treatments. Contrary to the CT treatments that had no crop residue retention, the plots were under clean tilled

agriculture only the crop was present and there was no food source except the crop itself for soil organisms (e.g. termites), and there was no habitat for predatory insects.

CA treatments further revealed that soil organic matter (SOM) and plant nutrients content was improved by crop residue retention. The increased biological activity with crop residue retention also enables the slow breakdown of the residues and their progressive incorporation into the soil as organic matter. Lack of tillage in CA systems meant that this SOM lasted longer in the soil as humus. And according to Thierfelder *et al.,* (2014), plant nutrients associated with humus are more available than inorganic forms of the same nutrients. Surface residues may, however, sometimes immobilize nitrogen, and in the first years of CA on much degraded soils, a little more manure or nitrogen fertilizer may be necessary (Mupangwa *et al.*, 2012). However, the results revealed that nitrogen management in the CA plots was attained through availability of crop residues and soil organic matter (SOM) that was gradually broken down by soil organisms and with time the nitrogen from the organic material was made available to the crops. Contrary to CT treatments this process was very fast and excessive such that SOM levels were reduced and the soils degraded in the process. And according to Wall *et al*, (2014) who reported that in very degraded soils with little SOM, the nutrient turnover may not be sufficient for crops, and it may be necessary to apply more nitrogen from manure, compost and fertilizer in the first years of CA.

In addition, crop residues retained on the soil surface of the CA treatments had positive effects on soil temperature. The crop residues shielded the soil surface from direct solar radiation, and so the soil did not heat up as much during sunny days of the cropping season. At night the crop residues further acted as a blanket, keeping the soil warmer. And the end result was that soil temperature was maintained in the CA treatments to support plant growth that consequently led to higher yields for both maize grain and biomass compared with CT treatments.

Thierfelder *et al.,* (2014), confirmed that other observed contribution to higher yields for both grain and biomass in CA treatments was increased water infiltration. The results revealed that in CA treatments, water infiltration increased as a result of the presence of

crop residues as mulch on the surface of the soil. In comparison with the CT treatments that had bare soils, surface aggregates were already weakened by tillage. And this was broken down by the explosive impact of heavy raindrops more especially for CPM1 treatment. Under CA treatments there were more soil pores created as a result of the increased biological activities with continuous residue cover and because the pores were not continually broken down by tillage. On the other hand, crop residues retention as mulch on the soil surface reduced moisture evaporation. It was clearly observed that surface residues were able to protect the soil surface not only from raindrops but also from radiation. Wall et al, (2014) similarly observed that radiation evaporates water, if you moves the residues aside you will normally find moist soil underneath. He further observed that residues also protect the soil surface from the drying effect of the wind.

On the other hand, variability existed on maize grain yield among treatments with highly significant difference between observed DS-MC and CPM1 treatments under CA and CT systems respectively (Figure 11). DS-MC treatment had higher measured maize grain compared with CPM1 treatment that had lower grain yield. The significant difference observed between the two treatments was attributed to the role CA played as its rotation effects could not be separated from the effect of tillage. This clearly explained why observed yields from the CA treatments with rotation were higher on the CA long-term trial at Msekera Research Station during the 2014/15 season. The combination of a leguminous rotational crop (cowpea) with maize added more nitrogen to the cropping systems, reduced pests and diseases such as Striga (*Striga asiatica L.*), a parasitic maize weed that is common in Zambia, and improved soil structure. According to Thierfelder *et al.*, (2014), who reported that under CA, rotations will often be better than a monoculture even if legumes are not included in rotation. He further suggested that, the best economic returns from rotations can be obtained if legumes are included because of the nitrogen they add to the system. Meanwhile, the study revealed that rotations alone were not sufficient to maintain high crop productivity, but extracted nutrients had to be replaced by fertilizers and/or manure. The two legume crops (cowpea and soybean) were rotated with the cereal (maize) in this study from the recommended growth strategy of nutrient accumulation versus nutrient depleting crops. Furthermore,

the combination took into account the importance of rotating different species, and especially species that have different pests and disease prevalence.

DS-MC treatment outperformed the other CA treatments even at on-farm trial management level where similar CA long term trials were setup under SIMLEZA project. And according to Thierfelder *et al.*, (2014) who reported that relative difference between all tested CA systems showed that most systems in the different target communities of Eastern Province of Zambia were above the 1:1 line with some few exceptions. He further reported that although there was within and between sites variability, overall CA treatments yielded more than the CT treatments; 80% of the data showed advantage of CA over CT. The maize yield for DS-MC was lower in the first and second growing season but increased in the third and four year of the CA long term trial at Msekera Research Station. This was attributed to the fact that preferred CA results are mostly not attainable in the first season. Generally, the maize yields from various CA treatments performed better than yields of farmers in Chipata district with observed 439 Kg ha $^{-1}$ average increase. However, in Zambia maize productivity is still low and the average yield is 1700 Kg ha $^{-1}$ (CSO report, 2013).Therefore, the measured field results confirmed that CA rotational treatment with cereals and legumes outperformed the other CA treatments at both on-station and on-farm CA long term trials. Mupangwa *et al.*, (2012) also confirmed that results from Kayowozi on-farm experimental site in Chipata district showed that maize yields in a Direct seeded CA treatment, using cowpea seeded with a dibble stick in full rotation, increased by up to 78% after four cropping seasons in comparison to a conventional control using a ridge and furrow system. As for CA treatment with maize intercropped with cowpea in order to benefit from both crops, the effectiveness of this strategy in controlling pests and diseases was uncertain. The treatment showed very strong competition between the cereal (maize) and the intercropped legume (cowpea). As a result, maize yields in DS-M/C was the lowest among the observed CA treatments during the 2013/14 season (Figure 10). This was attributed to the fact that crops grown as intercrops should be of different growth habits, canopy structure and rooting architecture. Maize in this case was intercropped with cowpea using Direct Seeder as a seeding technology. Under this treatment relay-intercropping was used to grow two crops (maize-cowpea)

simultaneously during part of the life cycle of each. The second crop (cowpea) was planted after ten days of planting the first crop (maize) but of course before reaching reproductive stage. Furthermore, spatial arrangement of cereal and legume crops in intercropping system was used with an arrangement of component crops in an alternating row manner with one row of cereal followed by a row of legume. The study observed that the 10 days phase seeding of cereal (maize) and legume (cowpea) crops in the intercrop treatment was too short and resulted in high competition between the two crops. This subsequently contributed to the low yields for biomass and grain obtained from CA intercropped treatments as compared to the others under the same cropping system. However, a high cereal and legume yield when compatible crop species are intercropped improves soil fertility when grain legumes or leguminous green manure cover crops are intercropped with cereals. And according to (Shitumbanuma *et al.*, 2014), intercropping helps to break the cycles of diseases, weeds and pests. Therefore there was need to increase the period between seeding of cereals and that of the legumes in this intercropping system in order to avoid intercrop competition for light and nutrients. But according to Wall *et al.*, (2014), when compatible crops are selected, no negative effects on crop growth and yield are experienced on different dates that is relay planting. The cereal is often seeded first and the legume can be seeded up to eight or more weeks after seeding the cereal depending on the species and purpose of the legume selected (Wall *et al.*, 2014). Hence, there is need to further carry out more research on the timing of the cereal and its associated legume crop in order to minimize competition for light at the initial stage of growth.

Snapp *et al.*, (2002) suggested that all the principles of CA systems should be practiced if the best returns are to be obtained from the cropping system. However, the profitability of the full rotation has to be taken into account (Snapp *et al.*, 2002). To support the results of this research, a detailed study undertaken at the Farmer Training Centre (FTC) in Monze district in Southern Province of Zambia revealed that CA treatments, especially that using cotton in rotation, increased water infiltration and soil moisture. In some years, infiltration was five times higher on CA fields than on those using CT system. And according to separate studies that revealed that CA systems showed great potential to mitigate the effects of seasonal dry-spells, as more infiltration

may lead to higher soil moisture availability for crops (Kassam *et al.*, 2012; Thierfelder and Wall, 2010a). Furthermore, research results from the tropics suggest that no-tillage with mulch and herbicide applications maintained and in some instances improved soil productivity and increased maize yields in comparison with CT (Ngwira *et al.*, 2013; Owenya *et al.*, 2011; Thierfelder and Wall, 2012). Also according to Ngwira *et al.*, (2012) they found that maize grain yield as well as biomass yield was higher under CA at Lemu Bazale EPA, 30 to 44 % higher with CA compared to CT.

4.2.3 Evaluation of the long-term effects of rainfall and temperature changes on crop yields under CA predicted using APSIM

4.2.3.1 Model calibration and simulation of long term CA effects under climate change

The total seasonal rainfall at Msekera Research station was 807.6mm with 57 rain days for 2014/15, and 937 mm with 70 rain days for 2013/14. The predicted comparisons between the observed and simulated results using linear regression statistical analysis on maize grain and biomass yields are shown in Figures 10 and 11. The long term effects of rainfall and temperature variability on grain (EF = 0.51) and biomass (EF = 0.98) yield were simulated for 85 years using five different climate change scenarios application. According to the linear regression (R^2) statistical analysis, APSIM model gave a good prediction on maize grain yield that was 74.8%. In general, a model fits the data well if the distance between the observed values and the model's predicted values are small and unbiased. Therefore, in this study R-squared was used to measure how close the data sets were to the fitted regression line. And the results showed no significant difference between the observed and simulated output. The model also predicted 28 growing seasons with below average maize grain yield from the 85 years.

The predicted mulching effect on maize grain and biomass yields in the four treatments of the 2014/15 season are shown in Figure 10. However, in 2014/15 seasons the model over-predicted biomass yield by 3.0 t ha^{-1} mulch cover (Figure 10). The R-squared generated for the comparison between observed and simulated results on biomass yield was low and account for 39.4%. Therefore, the over-prediction of biomass yield results

by the model was attributed to the poor performance of the model that had low R-squared. And according to Antonopoulos, (1997) who reported that with APSIM crop modeling, the Coefficient of Residual Mass (CRM) is an indicator of the tendency of the model to either over or under predicts measured values. He further reported that a positive value of CRM indicates a tendency of underestimation, while a negative value indicates a tendency of overestimation. In another similar statistical analysis using CRM confirmed that the value obtained for biomass yield under APSIM model at Msekera Research Station was -1.03. In this case the higher the negative CRM value the more over-prediction was the simulated result. In addition, the over-prediction of the biomass yield by the APSIM model was also attributed to its failure to recognize some variability that existed in the environment. These variability includes severe moisture deficit that characterized the season most especially during the prolonged dry spells. The prolonged dry spells experienced at Msekera Research Station affected the grain filling stage for maize crop. Furthermore, the over-prediction of the biomass yield by the model correlated with the assessment of its accuracy through the Root Mean Square Error (RMSE) that was above 30% and represented fair to poor performance of the model.

The model predicted that there will be approximately 0.4% increase in maize grain yield on average for CA treatments when 11.3% increase in rainfall (CC1-11.3 percent increase in rainfall) climate change scenario was applied to the model. Mkonga *et al.*, (2013) also confirmed that the increase in yield on CA treatments does not necessarily depend on the increase in rainfall. In addition, the model predicted an average increase in maize crop yield for CA treatments of 4% (171 Kg ha^{-1}) with the application of 11.3% decrease in rainfall (CC2-11.3% decrease in rainfall) as climate change scenario. The model prediction on the decrease in cumulative rainfall or drought consistently confirms the potential of CA to off-set the future effects of climate change on crop productivity. And according to the finding of Dimes *et al.*, (2010) that revealed that APSIM output showed that increasing CO_2 concentrations increased maize crop yields in the order of 6–8%. The simulated results revealed that reduction in annual rainfall had a positive impact on maize grain yield. However, Dimes et al., (2010) concluded that it is increasing of temperature and not reducing rainfall that has the most dramatic impact on

crop grain yields with simulated results showing a reduction of 16% for the two cereals (maize and wheat), 31% for groundnut, but only 3% for pigeon pea respectively. On temperature, the model predicted an 11% (454 Kg ha-1) decrease in average maize grain yield for CT treatment when 1 ^{o}C increase (CC3-1 degree increase) climate change scenario was applied to the crop simulation model. The results further revealed that there were significant decrease in average maize grain yield for CT treatments as compared to the CA treatments when temperature was raised as climate change scenario. The study suggest that in future smallholder farmers who will want to continue practicing CT should not adopt longer duration cultivar rather than shorter duration germplasm. The shorter duration germplasm will seem to be more appropriate response in dealing with the effects of climate change. Another preliminary indicator is that opportunities for increased cropping intensity and accelerated use of legumes in the farming system could emerge under climate change. Furthermore, the APSIM model predicted a of 21% (868 Kg ha^{-1}) decrease in average maize grain yield when 2 ^{o}C increase in temperature (CC4: 2 degree increase) was applied as climate change scenario. The simulated results further revealed a 31% (1278Kg ha^{-1}) when 3 ^{o}C increase in temperature (CC5-3 decrease increase) was applied as climate change scenario respectively. In support of the model's prediction, Tumbo *et al.*, (2010) observed that maize grain yield in the future seasons are only expected just below 2 t ha^{-1} for CT practice as a result of climate variability. He further reported that, probability of maize grain yield gain of 2 t ha^{-1} is quite significant in the long period of CA practice adoption in future amidst climate change.

According to IPCC, (2001) report that suggested that global surface air temperature may increase by 1.4 ºC to 5.8 ºC at the end of the century. Tumbo *et al.*, (2010), confirmed that CA practices stand a greater chance to adapt to climate change at least by 2050, where temperature is projected to increase by 2 ºC and rainfall to increase by 56 mm during the long rainy season. Therefore, this temperature rise prediction will greatly contribute to decrease in crop yield mostly for major crops like maize that is a staple food for most Southern African countries. Suffice to mention that despite the decrease in maize grain yield in response to temperature rise, CA will continue to perform better than the CT practices as shown in the results of this study. And according to Watson *et al.*, (2000) who reported that for temperature increase to above 3 °C, yield losses are

expected to occur everywhere and be particularly severe in tropical regions. He further reported that in parts of Africa, Asia, and Central America yields of wheat and maize could decline by around 20 to 40 percent as temperature rises by 3 °C to 4 °C, even assuming farm-level adjustments to higher average temperatures. The decrease in cumulative rainfall has no significant impact on grain yield and productivity as it led to an increase in maize crop yield especially as predicted by the model for 85 cropping seasons under the three CA treatments. By adopting CA practices in a long run, higher maize yields are predicted compared to the CT practices, averaging 24-30% estimated increases in the long run. Therefore, the findings of the study emphasizes on the need to continue practicing CA in seasons to come so as to expect much better crop yields than the current situation in relation to maize production. However, the largest scope for dealing with reduced crop yields and food insecurity under future climate change is to raise the productivity of smallholder rain fed cropping systems in Zambia.

4.2.4 Evaluation of the long-term effects of rainfall and temperature changes on soil water under CA predicted using APSIM

The comparison between observed and simulated results for soil water using the linear regression had a high R-squared value. The R-squared in this case accounted for 91.4%. This meant that the model performed very well with the R-squared value closer to 100%. Higher soil moisture was predicted in CA treatments at depth layers especially in the direct seeded treatments under the prevailing conditions at Msekera Research Station (Figure. 18). The highest observed soil water (esw) was recorded in DS-MC treatment and the lowest in BAM treatment. The simulated results for maize grain yield positively correlated with the simulated results for soil water using the APSIM model. The long term crop simulated model predicted no significant difference in soil water between the CT treatment and the CA treatments.

Generally, there was a close correlation between simulated and observed volumetric soil moisture content in the profile layers for the four treatments during 2014/15 season. Also the soil moisture simulations highly corresponded to the trend of rainfall events at Msekera Research Station, especially for the top 600 mm of soil. This also confirmed that the APSIM model can simulate soil water reasonably well as evidenced from the

aforementioned reason. In addition, the APSIM model correctly simulated the soil moisture in this study with the mean NRMSE of 8.62% and R-squared value of 91.4% that represented a very good to excellent performing model. The result showed that the observed and simulated soil moisture content was closely to each other (Figures 18).

The APSIM model simulated that rainfall had a positive effect on the soil water accumulation mostly for CA treatments. Increase in annual rainfall had an advantage on CA treatments as the soil water accumulation was equally increased and coupled with the presence of crop residue on the soil surface improved soil water storage. Reducing the annual rainfall in the crop simulation model by 11.3 % as climate change scenario showed no significant effect on soil water accumulation in the CA treatments. Furthermore, when temperature was raised from 1 to 3 ^{o}C, there was no significant decrease in soil water accumulation in the CA treatments. However, the CT treatment had significant effects of raised temperature as compared to CA treatments.

During the drying out phases after the cropping season, APSIM model simulated that direct seeder maize-cowpea rotation (DS-MC) treatment maintained more soil moisture than the other CA and CT treatments as a result of available crop residue cover on the soil surface that was able to maintain good and conducive temperature. The basins with maize (BAM) treatment under CA system maintained the lowest moisture content at drying out period among the three CA treatments. This was contrary to the principles of CA in most cases. There was a positive correlation on the simulated APSIM outputs between the maize grain yield and soil water in this experiment as was analyzed using the linear regression. However, on average, the first two layers at 10-20 cm and 20–30 cm were particularly interesting in this comparison, with a greater distinction between treatments. When all four layers were combined into one soil moisture profile of 0–40 cm, it was observed that the three CA treatments had more moisture (in mm) than the conventional control plot.

The presence of soil moisture in the CA treatments confirmed that this technology has higher potential to mitigate the effect on climate change on crop production and water harvesting. The APSIM model also revealed that soil moisture retention in CA

treatments was not affected by drought but slightly as a result of increase in temperature. And according to the study by Chen et al., (2013) who reported that APSIM model showed promise in simulating soil water balance, crop growth and grain yield measured in the field experiments for different cropping systems and CA technologies in the Loess Plateau of Gansu in China. In addition, Connolly *et al.*, (2002) also reported that APSIM model generally simulated infiltration, runoff, soil water and water balance, and yield as accurately and reliably as other soil crop models. He was able to demonstrate that the model is suitable for evaluating effects of infiltration and soil water relations on crop growth. However, the long term simulation on the effect of rainfall and temperature on soil water revealed that out of 85 years simulation 22 seasons will experience adverse drought and that will consequently result in yield reduction most especially for the CT practices.

Abrol and, Sunita (2005), suggested that if CA is adopted in a comprehensive way over a period of time it will brings multiple benefits that minimizes soil loss, conserve water, control weeds enrich SOC and increase productivity in the face of challenges facing the agriculture sector. CA is the only resilient farming practices for smallholder farmers during the simulated 22 years of adverse drought period. Moreover, access to perennial surface water will be particularly vulnerable in semiarid regions, especially in parts of Africa and Zambia inclusive. Furthermore, a consortium of CA authors (McKeon *et al.* 1993; Chattergee and Huq 2002, Mortimer and Manvel, 2006) collectively suggested that it is now widely accepted that by focusing on improving the resilience of the current production systems and smallholders' risk management strategies in the short term, we can support adaptation to longer-term effects of climate change in agriculture. Therefore, in all affected regions, the poor smallholder farmer will be disproportionately vulnerable to the effects of drought as a result of their dependence on rain fed agriculture and their lower capacity to adapt. Furthermore, according to UNECA, (1999) report that projected that in Africa specifically, the combined impacts of climate change and population growth suggest an alarming increase in water scarcity for many countries, with 22 of the 28 countries considered likely to face water scarcity or water stress by 2025.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Conservation Agriculture aims at increasing crop productivity and production mostly among smallholder farmers in Sub-Saharan Africa. The anticipated long-term CA intervention will increase adoption of resilient farming systems leading to improved food supply, reduce hunger, counter rising food prices, and improve responses to food emergency crisis by extending the area of land under CA practices.

The canopy analysis on the effect of treatment on maize yield through a NDVI revealed that CA treatments had greener vegetation compared to CT treatments. CA treatments had higher positive NDVI values an indication of healthier maize with more chlorophyll for plant growth. NDVI analysis positively correlated to maize grain and biomass yields for observed treatments. In addition, NDVI analysis proved to be a very helpful tool in estimating photosynthesizing ability of plants, primary production, and maize yield.

Furthermore, the performance of the APSIM model on crop simulations was perfect on the effect of rainfall and temperature changes on both crop yields and soil water dynamics under CA practices. Even though the APSIM model over-predicted maize biomass yield as a result of failure to recognized some variability that existed in the environment during the 2014/15 season at Msekera Research Station. The variability includes the severe moisture deficit that characterized the season most especially during the prolonged dry spells. The crop simulation model was performed for 85 seasons and the simulation model outcome considered five rainfall and temperature related climate change scenarios. The reduction on the amount of rainfall under simulation had a positive effect on crop production has it raised maize grain yield by 4% on average for CA treatments. Nevertheless, the research revealed that increase in temperature had a negative effect on maize crop yield for CT treatment. Increase in temperature to 3 ^{o}C resulted in average maize crop yield decrease of up to 31 % compared with the baseline no climate change. Moreover, under the same climate change scenarios, the ASPIM

model similarly simulated high soil moisture under CA treatments compared with CT treatment. The long term simulation on the effect of rainfall and temperature on soil water also revealed that out of the 85 years predictions, 22 seasons will experience adverse drought and that will consequently result in yield reduction especially for the CT practices. Nevertheless, the long-term future climate change simulations revealed that CA was less vulnerable to climate variability expressed by higher yields in drier seasons compared to CT practices. Similarly, cumulative probability distribution indicated that CT was more of a risky system compared with CA systems.

Therefore, the study has proved that adoption of CA systems in Eastern Province of Zambia will prepare smallholder farmers for the anticipated future threats of climate variability and changes in agriculture sector. While application of full principles of CA system indicated benefits in terms of less vulnerability to lower grain yields in dry seasons like the current one that had more than 21 days prolonged dry spell.

5.2 Recommendations

CA is a strategic approach in mitigating the future effects of climate change, preserving soil fertility, and soil water resources by smallholder farmers. Therefore, the study recommends to smallholder farmers to adopt CA and start enjoying the various benefits that come with this technology, such as increased yields, improvement of soil fertility, and moisture retention, among others.

In order for smallholder farmers to take up these resilient technologies described in this study, there is need for concerned researchers to develop appropriate field equipment, which are gender sensitive to allow these systems to be successfully adopted by farmers.

Furthermore, in order to overcome traditional mindsets among smallholder farmers on conventional tillage, the study recommend promotion of farmer experimentation with the described technologies in a participatory manner to help accelerate adoption.

The study revealed that NDVI can used to estimate growth and crop yield. Therefore, there is need to adopt the use of NDVI to provide very useful information for agricultural drought monitoring and early warning system for the farmers.

The study has proved that APSIM model can be used in crop simulation in relation to climate change. Therefore, similar studies to be conducted over a wider range of crop simulation models and in the various agro-ecological regions.

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APPENDICES

Appendix 1: Analysis of variance (ANOVA) for Normalized Difference Vegetation Index (NDVI) based on crop growth development between conventional and CA practices at Msekera Research Station

Source of variation	Degree of Freedom	Sum of squares	Mean squares	F-value	P-value
Replication	3	0.012121	0.004040	0.86	
Treatment	9	2.469491	0.274388	58.27	0.001
Days after Planting (DAP)	6	3.293532	0.548922	116.57	0.001
Treatment. DAP	54	4.023704	0.074513	15.82	0.001
Residual	207	0.974779	0.004709		
Total	**279**	**10.773627**			

Appendix 2: Analysis of variance (ANOVA) for field observed maize biomass yield (kg ha^{-1}) at Msekera Research Station

Source of variation	Degree of Freedom	Sum of squares	Mean squares	F-value	P-value
Replication	3	13439274	4479758	11.62	0.001
Treatment	7	7996675	1142382	2.96	0.025
Residual	21	8094117	385434		
Total	**31**	**29530067**	**952583**		

Appendix 3: Analysis of variance (ANOVA) for field observed maize grain yield (kg ha^{-1}) at Msekera Research Station

Source of variation	Degree of Freedom	Sum of squares	Mean squares	F-value	P-value
Replication	3	9608066	3202689	8.00	0.001
Treatment	7	12857084	1836726	4.59	0.003
Residual	21	8408920	400425		
Total	**31**	**30874070**			

Appendix 4: Statistical result comparison between simulated and measured maize grain yield in both conventional tillage and CA for 2014/15 season

Treatment	Observed (Kg ha^{-1})	Simulated (Kg ha^{-1})	RMSE	EF	NRMSE (%)
Conventional Ploughing	1941.15	3380.8	1017.90	0.94	38.07
Basins	2946.2	3476.0	374.60	0.76	14.01
Dibble Stick	3054.0	3483.6	303.77	0.22	11.36
Direct Seeder	2752.7	3688.1	717.42	0.10	26.83
Mean	2673.51	3507.13			

Appendix 5: Statistical result comparison between simulated and measured biomass yield in both conventional tillage and CA for 2014/15 season

Treatment	Observed (kg ha^{-1})	Simulated (kg ha^{-1})	RMSE	EF	NRMSE (%)
Conventional Ploughing	2144.2	5603.0	2445.88	0.99	96.74
Basins	2373.0	4872.9	1767.69	0.99	69.92
Dibble Stick	2914.8	4934.3	1428.00	0.96	56.48
Direct Seeder 69.6	2681.2	5169.7	1759.63	0.99	
Mean	2528.3	5144.96			

Appendix 6: Statistical result comparison between simulated and measured soil water in both conventional tillage and CA for 2013/14 season

Treatment	Observed (mm)	Simulated (mm)	RMSE	EF	NRMSE (%)
Conventional Ploughing	76.98	65.29	8.26	0.90	11.27
Basins	62.79	66.31	2.49	7.80	3.40
Dibble Stick	67.66	66.14	1.08	14.0	1.47
Direct Seeder	85.73	66.07	13.44	0.60	18.34
Mean	73.29	65.95			

Appendix 7: Showing the Analysis of variance (ANOVA) for observed and simulated biomass yield

Variate: Biomass Yield

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	1		1739139.	1739139.	38.61	
Rep.*Units* stratum						
Treatment	3		457702.	152567.	3.39	0.172
Measurement (obs vs. simld)	1		31789944.	31789944.	705.68	<.001
Treatment x Measurement	3		907706.	302569.	6.72	0.076
Residual	3	(4)	135146.	45049.		
Total	**11**	**(4)**	**18569924.**			

Appendix 8: Showing the Analysis of variance (ANOVA) for observed and simulated maize grain yield

Analysis of variance

Variate: Maize Grain Yield

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	1		2040023.	2040023.	49.65	
Rep.*Units* stratum						
Treatment	3		1646177.	548726.	13.36	0.031
Measurement (obs vs. simld)	1		6300827.	6300827.	153.36	0.001
Treatment x Measurement	3		880640.	293547.	7.14	0.070
Residual	3	(4)	123259.	41086.		
Total	**11**	**(4)**	**5771773.**			