EFFECTS OF SELECTED CONVENTIONAL AND CONSERVATION AGRICULTURE ON SOIL MOISTURE CONTENT, INFILTRATION AND MAIZE AND PEARL MILLET GRAIN YIELD IN LISELO AND MASHARE: NAMIBIA

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LADISLAUS P. KUDUMO

201117479

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SUPERVISOR:

PROFESSOR F. ITANNA

UNIVERSITY OF NAMIBIA, FACULTY OF AGRICULTURE AND NATURAL RESOURCES, CROP SCIENCE DEPARTMENT

CO-SUPERVISOR:

DR. J. KAMBATUKU

UNIVERSITY OF NAMIBIA, FACULTY OF AGRICULTURE AND NATURAL RESOURCES, INTEGRATED ENVIRONMENTAL SCIENCE DEPARTMENT

Abstract

This study focused on the results from the 2016/17 and 2017/18 cropping seasons from two trials, one in Liselo and the other in Mashare in the Kavango East and Zambezi regions of Namibia, respectively, on the effects of Conventional and Conservation Agriculture (CA) practices and principles on soil moisture content and infiltration. Conventional mouldboard ploughing (CTa), Sub-soiling with a Magoye ripper (SS-M) and Manual direct seeding with a Dibble stick (MDS-M) were the primary treatments of interest in the CA Systems Trial. In Both seasons, average soil moisture content, total water infiltration and runoff were not significantly affected by tillage systems treatments. The treatments of interest in the Component Trial were Conventional tillage (CT), Minimum tillage (MT), Minimum tillage, mulch (MT-M), Minimum tillage, rotation (MT-R) and Minimum tillage, mulch and rotation (MT-MR) were. Significant differences (p=0.000) were observed with regard to soil moisture content in the 0-30cm and 0-60 cm soil depths on the Component Trial at both sites.MT-M plots had the highest soil moisture content of 14.5mm and 39.8mm at Liselo Research Station (LRS) and 44mm and 134.5 mm at Mashare Irrigation Training Center (MITC) for the 0-30cm and 0-60cm soil depths, respectively over the study period. Conventional Tillage (CT) with a mouldboard plough in both localities LRS and MITC had lower average soil moisture content in both 0-30cm and 0-60cm soil depths than most CA treatments. Regarding the Component Trial, a significant difference on grain yield was only observed at MITC in the first season (p=0.0496) and in the second season at LRS (p=0.0206). CT(1783.0 kg ha^{-1}) had the highest pearl millet grain yield, followed by MT-M (1562.0 kg ha^{-1}) and MT (1520.8 kg ha^{-1}) had the lowest pearl millet grain yield. CT (3852.3 kg ha^{-1}) had the highest maize grain yield and MT (2524.0 kg ha^{-1}) had the lowest maize grain yield. Results suggest CA has the potential to increase water conservation and contribute to reduction of risk of crop failure, as was observed at MITC where CA plots had more soil moisture content than conventionally tilled plots.

Keywords: Conventional Tillage, Conservation Agriculture, grain yield, run-off, soil moisture content, total infiltration.

List of Publication(s)/Conference(s) proceedings

1. Effects of conventional agriculture and conservation agriculture on soil moisture content, infiltration and yield in Liselo and Mashare: Namibia, 1st International Conference on Agriculture and Natural Resources,16-17 October 2017,Ogongo Campus, University of Namibia, Theme: "Resilience of livelihoods in a changing climate in Southern Africa"

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List of Abbreviations

ANOVA	Analysis of Variance
a.s.l	Above sea level
ACN	Adapting agriculture to climate change in northern Namibia
BP	Basin Planting
CA	Conservation agriculture
CIMMYT	International Maize and Wheat Improvement Center
CT	Conventional Tillage
Cta	Conventional ploughing (mouldboard, animal traction)
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HIV	Human Immunodeficiency virus
IPCC	Intergovernmental Panel on Climate Change
LRS	Liselo Research Station
MAWF	Ministry of Agriculture, Water, and Forestry
MDS-D	Manual direct seeding with a Dibble stick
MET	Ministry of Environment and Tourism
MITC	Mashare Irrigation Training Center
MoHSS	Ministry of Health and Social Services
MT	Minimum Tillage
NNF	Namibia Nature Foundation
NPK	Nitrogen, phosphorous, potassium
NSA	Namibia Statistics Agency
NUST	Namibia University of Science and Technology
RIBA	Ripping with a Baufi animal traction ripper
RIBA-C	Ripping with a Baufi animal traction ripper – Cowpea intercrop
RIBA-L	Ripping with a Baufi animal traction ripper - Lablab

	intercrop
SSM	Sub-soiling with a Magoye ripper
UK	United Kingdom
UNAM	University of Namibia

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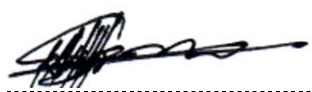
Dedication

I would like to dedicate this work firstly to my Lord, God, to my father, my family, my beloved Girlfriend, my daughter and all the people that have helped me to reach this point, those that have walked beside me, helping and guiding me as I walked this path.

Declarations

I, Ladislaus Pandura Kudumo, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

I, Ladislaus Pandura Kudumo, grant The University of Namibia the right to reproduce this thesis in whole or in part, in any manner or format, which The University of Namibia may deem fit.

Ladislaus . P. Kudumo		*23/02/2019*
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1 Introduction

1.1 Background of the Thesis

1.1.1 Background of Namibia

The agricultural sector of Namibia is particularly affected by climate change, in the form of droughts, erratic rains and floods, which all are the major threats affecting food, water security and general livelihoods. Droughts, erratic rains and floods lead to failed harvests, and decreases numbers of livestock and products. Soil degradation and desertification are also increasing threats to the productivity of Namibia's agricultural sector.

In Namibia, pearl millet, locally better known as Mahangu is the staple food crop, grown largely for home consumption predominantly in the north-central regions of Namibia, while maize (*Zea mays*) is the staple food crop of the north eastern regions of the country, particularly Zambezi region. Another cereal crop that is less so produced in Namibia is sorghum. In 2012, Namibia alone imported 42 800 tonnes of pearl millet (NEWFIU, 2012).

According to the 2009 report by the Food and Agriculture Organization of the United Nations (FAO), the average annual pearl millet (*Pennisetum glaucum*) and maize production in communal areas in 2008 in Namibia was about 250-400 kg ha^{-1} and 500-550 kg ha^{-1}, respectively. According to Namibia's Country Climate Smart Agriculture Programme, jointly implemented by Ministry Of Agriculture Water And Forestry (MAWF) and Ministry Of Environment And Tourism (MET) (2015 – 2030), through the influence of climate change, it is projected that crop production is expected to decrease by at least 50% or more. Maize in particular expected to experience a 0.5 t/ha yield decline based on the above mentioned projections. Besides impacts by climate change and erratic weather conditions, the widespread use of outdated traditional farming practices has been identified as the main driver of low agricultural outputs (FAO, 2009).

Ploughing using the mouldboard plough, animal or tractor drawn and disking grinds the soil, in the process leads to reduced pore space, soil carbon content and may cause soil erosion by water and wind which may eventually lead to desertification.

Planting holes can be prepared using a hand hoe by digging holes enough for seed and fertilizer only (Nyanga et al., 2012). They can also be prepared using a simple dibble stick to prick a hole deep and wide enough for both seeds and fertilizer and using rippers to prepare riplines for planting of crops such as maize (*Zea mays L*.), groundnuts (*Arachis hypogaeaL*.), sorghum (*Sorghum bicolor (L*.) Moench), and many other crops (Twomlow, Urolov, Oldrieve & Jenrich, 2008).

Average annual national rainfall in Namibia varies from less than 20 mm towards the Atlantic coast to above 600 mm in the northern regions with only about eight percent (8%) of the country receiving more than 500 mm as average annual rainfall. In the same way, the Annual National Temperatures in Namibia can range from under 0°C to well over 40°C, with potential evaporation rates high ranging from 2,600 mm in the northern areas to 3700 mm per annum in the central-southern areas of the country.

Climate change has become one of the greatest challenges of mankind in the 21st century, so much more so that the Intergovernmental Panel on Climate Change (IPCC) in recent studies had suggested that by the year 2050 rainfall and temperatures over southern Africa in particular are to be 10 – 20% less and 2 – 4°C higher; respectively, as compared to the 1961-90 baseline. Midgley, Hughes, Thuiller, Drew & Foden (2005) and Rowswell and Fairhurst, (2011) highlighted that, due to climate change, mitigation is even more of a need in agriculture as erratic weather patterns are projected to become increasingly worse. Purcell, Edwards &Brye (2007) highlighted that soil moisture stress resulting from drought, dry spells and high moisture loss through evaporation is one of the primary limiting factor in crop production as it affects many plant biochemical and physiological processes.

Conservation of natural resources in recent decades has developed into a key global objective and a major national aim for Namibia as well. Soil is a very valuable natural resource, and in the face of climate change it must be well managed and maintained in a way that can maintain its resilience. For sustainable and booming agricultural crop productivity, it is critical that good maintenance and improvement of soil quality is done (Fourie, Agenbag & Louw, 2007). The use of land and its resources must be continuously and thoroughly monitored and managed. Ekins, (2011) stated “It is an elementary fact that economic activity is absolutely dependent on the goods and services supplied by the natural environment”.

To ensure continued crop production and economic prosperity, parties involved in agriculture must content with fact of our reality; that our natural environment is changing and that increasing natural disasters like low and variable rainfall are the major obstacles to optimum nationwide agricultural production.

Conservation agriculture (CA) involves a combination of soil management practices to reduce soils disruption, compaction and enhance natural biodiversity.CA is based on three principles namely (1) minimal soil disturbance, (2) crop rotation and (3) permanent soil cover with crop residues or growing plants(Kassam, Friedrich, Shaxson, & Jules, 2009; FAO, 2009; & Friedrich, Derpsch, &Kassam, 2012).

In Namibia, tillage is largely done using the hand hoe and animal drawn mouldboard plough introduced in the early 20th century from Europe usually referred to as Conventional Tillage (CP). Conservation Agriculture in Namibia was introduced in 2005 by the Ministry of Agriculture, Water and Forestry (MAWF) and the Ministry of Environment and Tourism (MET) with a focus at the time on the Kavango region through demonstration plots. In those limited areas especially during drought, farmers who practiced conservation agriculture are reported to have a much higher grain yield, for example pearl millet’s grain yield increased from 300 kg ha^{-1} under traditional farming methods, to 2000 kg ha^{-1} using conservation agriculture practices. Another project which took on conservation in agriculture in Namibia was started in 2012 called the Namibia Conservation Agriculture Project (NCAP) and was designed to run for 3.5 years. It was implemented by CLUSA International, in collaboration with Creative Entrepreneurs Solutions (CES), a Namibian NGO based in Ondangwa. The project was funded by the USAID Office of Foreign Disaster Assistance. Through the project, it was observed that the national average pearl millet yield of 0.23 t/ha at the time could be hugely improved to 1.5t/ha (Mallet, du Plessis, 2001; NCBA, 2012). Namibia has also developed a Namibia specific conservation tillage (NSCT) technique as a method that advocates for use of rippers, mulch, improved seeds, constant monitoring, new planting and fertilizing methods and techniques.

1.1.2 Background

This thesis reports on the effects of Conventional and Conservation Agriculture (CA) practices and principles on soil moisture content and infiltration during the 2016/2017 and 2017/2018 cropping seasons from two trials in two sites; one site, the Liselo Research Station (LRS) and the other Mashare Irrigation Training Center in the Zambezi regions and Kavango East, respectively. The trials were established as part of the project titled “Adapting agriculture to Climate change in Northern Namibia (ACN)” in 2015 funded and monitored by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), in collaboration with the Namibian Ministry of Agriculture, Water, and Forestry (MAWF), CIMMYT, the University of Namibia (UNAM), and Namibia University of Science and Technology (NUST).

The trials were developed to monitor the short-term effects of conventionally tilled systems versus CA on soil quality and crop productivity under conditions of the major cropping systems in central, north-central and north-eastern regions of Namibia. The objective of this study was to test the hypotheses that (a) CA treated plots have a significant higher water infiltration and soil moisture content (b) the CA principles (minimum tillage, soil cover and crop rotation or intercropping) have a significant influence on soil moisture content eventually leading to greater crop productivity.

1.2 Statement of the problem

Dry spells, water scarcity, unreliable rain pattern and agricultural systems play a large role in the amount of moisture available in the soil. It is reported from Eastern and Southern Africa that 10–25% of rainwater is lost to runoff, and another 30–50% is lost through evaporation from unprotected soil surfaces. Namibia is classified as the driest country in Southern Africa; one has to note that loss of water plays a significant role in the already dry country. Different tillage methods have been found to have varied effects on the soil and its physical properties. Conventional tillage is widely practiced in Namibia and is being associated with increased soil erosion, loss of soil organic matter and destruction of soil structure as it turns over and exposes the soil. Minimum soil disturbance also referred to as minimum tillage is one of the tillage methods that is said to have beneficial effects on soil moisture storage, soil temperature and soil carbon. In Namibia, conventional agriculture has for decades existed as the major agricultural system up to the year 2005, in which the government through MAWF introducing another agricultural system namely CA. Unfortunately due to variable findings and little documented knowledge of the influence of Conventional and CA Tillage systems and principles on soil moisture content and water infiltration in Namibia, it is therefore necessary to research on suitable tillage methods for two agro-ecological north eastern regions of Namibia.

1.3 Objectives of the study

1.3.1 Overall objective

To document and compare the effects of different tillage systems (Conventional and CA) and the influence of the individual CA principles on soil moisture and infiltration.

1.3.2 Specific objectives

1. To determine effects of different reduced tillage options on soil moisture dynamics and water infiltration under maize, millet on a sandy soil;
2. To determine effects of minimum tillage and mulch/rotation on soil moisture and grain yields of maize and pearl millet.

1.4 Hypothesis of the study

Ho1: There are no significant differences in soil water infiltration between CA and Conventional plots

Ho2: There are no significant difference between the effect of no mulch, mulch only, rotation only and mulch plus rotation on the soil moisture content and crop grain yields for both CA and Conventional plots.

1.5 Significance of the study

Taking into account Namibia's dry climatic condition, it is important to determine and document the effects of Conservation Agriculture practices on soil moisture and crop production so as to encourage water conservation and good crop production for small holder and commercial farmers. Information on these effects can be highly useful in influencing further adoption of CA systems in Liselo, Mashare, Kavango East region, Zambezi region and Namibia at large.

2 Literature Review

In the following chapter the reader will be introduced to literature, fact, ideas and findings reviewed, providing descriptive and argumentative information on the state of Namibia, Conservation Agriculture (Its origin, definition, principles and its adoption), Tillage methods and their effect on soil moisture, Tillage systems and planting stations, Benefits of Conservation Agriculture (CA), Soil Cover and Residue Retention and lastly Soil Moisture and Infiltration.

2.1Conservation Agriculture: Origin, Definition, Principles and its Adoption

Conservation agriculture (CA) is a crop management system based on three principles namely (1) minimal soil disturbance, (2) crop rotation or intercropping and (3) permanent soil cover with crop residues or growing plants (Kassam et al., 2009;FAO, 2009; & Friedrich et al.,2012).

Complementary to CA, one finds Conservation tillage which is an important aspect of CA, an ecological approach to soil surface management and seedbed preparation, usually involving aggressive mechanical inversion of the soil (Busari, Kukal, Kaur, Bhatt & Dulazi, 2015). Conservation tillage is divided into three major categories: (i) No till in which no plow or disk is used and targets 30% or greater ground cover. (ii) Strip tillage in which the crops being planted in strips (iii) Ridge tillage which is a combination of no-till and conventional tillage and the crops are planted in ridges(Mahdi et al., 2009).

Reicosky (2015) states that the first use of the now known catchphrase “Conservation Agriculture (CA) ” originated from a Latin American Network for Conservation Tillage meeting funded by the Food and Agriculture Organization of the United Nations (FAO) that was held in Morelia, Michoacán, Mexico, in 1997. Conservation Agriculture in Southern Africa has not been very common practice, although considerably and successfully adopted in countries like Zambia (Haggblade & Tembo, 2003), and Zimbabwe (since 2004) on small pieces of farmland on smallholder farms.

Wall (2007), described that a switch from the Traditional/Conventional Tillage (CT) to CA is reported to be a difficult transition with importance always paid to a strong community based extension approach to achieve CA adoption. Conservation Agriculture like any management practice has a range of benefits, namely increased soil water infiltration, increased soil organic matter, reduced evaporation, reduced water run-off and soil erosion. Most benefits of CA especially improvement of the soil's physical properties are though only enjoyed in the longer term (Derpsch, 1999; Sayre, 1998), 4-5 years after application of such soil tillage system (Håkansson, 1993;Thierfelder, Matemba-Mutasa, & Rusinamhodzi, 2015). Challenges often faced by those involved in CAare the management of weeds, nitrogen levels in the soil and residue retention. Conservation Agriculture challenges are often experienced at the start of the endeavor whilst some benefits like reduced runoff and soil erosion may be also experienced almost immediately (Derpsch, 1999; Sayre, 1998).

Conservation agriculture is reported to be most effective when all three principles are being put into practice and good timing of all operations is conducted, (ZCATF, 2009).According to Friedrich (2007), farmers have developed a liking to CA because it gives them a means of improving, conserving and making more efficient use of natural resources at their disposal in their areas and surrounding areas (FAO, 2006).

Adoption of CA by subsistence farmers continues to be a challenge as farmers are known to be people who often adopt complex technologies in a step by step fashion to avoid getting confused and understand the technology well (Rogers, 1983;Aune & Bationo, 2008). All too often farmers may experiment with the technology, and in the end select the most preferred principles of CA rather than adopting all three principles of CA at once as a package. Baudron et al., (2007) and Mazvimavi and Twomlow, (2009), acknowledged that minimum tillage is rarely practiced on land exceeding 1 ha of the farming land per farming household. Muliokela, Hoogmed, Steven, & Dibbits, (2001) further highlighted that in southern Africa high weed density scores were associated with minimum tillage and this was the key problem, as farmers wanted technology that would reduce work and not create some. Out of the global 106 million ha reported to be under Conservation Agriculture worldwide, Africa contributes a mere 0.4 %, with the majority adopters being commercial farms in South Africa (Kassam *et al*., 2009; Kassam, Friedrich, & Derpsch, (2018).

2.2Tillage Methods and Their Effect on Soil Moisture

Tillage is described as the preparation of the soil for the production of crops for human consumption, animal feed and/or for the improvement of the soil. Tillage is known to influence physical soil properties. Tillage influences soil hydraulic properties such, which determines the ability of the soil to capture and store water from precipitation or irrigation, change flow path and rate of water and the stability of the biotic factors, all playing a significant role in agricultural production system (Dexter, 1988).

Tillage comes in many types, forms and variations influencing the soil physical properties in different ways. Based on percentage residue cover left on the soil surface, tillage methods are divided into three main categories: the first category is intensive tillage usually referred to as conventional tillage where less than 15% crop residue are left on the soil surface and soil is inverted completely. The second category is reduced tillage where percentage residue cover is 15% to 30%, usually involving the use of field cultivators and chisel plows. The last category is no tillage which leaves a percentage residue cover of 30 % or greater or in which the soil is not turned over and crop residues are removed. Conventional tillage is described as the preparation of the soil for cropping through the use of the mouldboard plough which was introduced in the 1920's from Europe.

No tillage is the preparation of the soil for cropping in which there is minimum to low soil disturbance for the conservation of soil physical properties, nutrients and water. No till, covers about 72 million hectares of agricultural land throughout the world (Derpsch and Benites, 2003); largely due to it having greater levels of profitability, in most cases a result of increased yields and lower input costs. No till is said to contribute to accumulation of organic matter, improving soil aggregation and structure over time and improving soil moisture storage (Jaipal, Singh, Yadav, Malik, &Hobbs, 2002;

Thierfelder, & Wall, 2009). The above mentioned benefits of no-tillage methods coupled with differences arising from implementation in different locations, implements used, skills used, ecological and soil factors such as soil texture (Kladivko, 2001).

Conservation tillage protects the soil from wind and water erosions through mulch (Morris, Miller, Orson & Froud-Williams, 2010), improves the biological properties of soil (Fernandez, Quiroga, Zorati & Noellemayer, 2010) and physical (Martinez, Fuentes, Silva, Valle &Acevedo, 2008), chemical properties(Guzman, Godsey, Pierzynski, Whitney & Lamond, 2006). Conservation tillage saves and conserves the soil moisture (Verch, Kachele, Holtl, Richter & Fuchs, 2009), reduces time taken for land preparation, and reduces the cost of production (Uzun,Yol, Furat, Topakçı, Çanakçı & Karayel, 2012).

The influence of tillage on crop growth and development is reported to however depend on crop species grown, the climatic conditions, the location of the site and time of application and type of tillage practice used to prepare the land (Martinez et al., 2008).Conventional tillage is the most common practice among small holder farmers and has been practiced for a long time (Chen,Liu, Li, Li, Song, Cruse, &Zhang2011).It is on the other hand reported to be unsustainable over the long term period in more intensive production systems as it contributes to inefficient natural resources use, poor soil water retention, and soil degradation and contribute to global warming (Ferna´ndez,Quiroga, Zorati, & Noellemayer, 2009).

Tillage methods (Fuentes,Flury, Huggins & Bezdicek, 2003),climatic factors especially rainfall distribution and reliability (Fowler & Rockstrom, 2001)influence available soil moisture which is key for plant growth and development and soil physical properties. Tillage methods and mulch/residue management have been reported to have beneficial effects on soil moisture storage (Gicheru, Gachene, Mbuvi & Mare, 2004; Benites, 2008; Landers, 2008).

Tools used for tillage include, rippers, jab-planters, mouldboard ploughs. A ripper is a implement used for land preparation. It is designed to opens narrow furrows that are about 5-10 cm deep, provide minimal disturbance and not turn over the soil like the mouldboard plough (Sims, Thierfelder, Kienzle, Freidrich, & Kassam, 2012).It is usually employed when the soil is dry and sowing of seed is done either by hand or by a planter attached to the implement. A jab-planter example is another type of implement used to provide reduced soil disturbance. A jab-planter has two tips that are cut at angles to allow it to cut into the soil creating a small hole enough to accommodate seed and fertilizer when planting (Aikins, Bart-Plange, & Opoku-Baffour, 2010) and lifted manually to cover the seed achieving minimum soil disturbance in the process (Ngwira, Thierfelder, & Lambert, 2012).

2.3Benefits of Conservation Agriculture (CA)

Conservation agriculture which is to be a less energy intensive as compared to conventional tillage has been shown to improve crop yields while conserving water and soil in many different agro-ecological zones of the world band has the potential to eliminate on-farm and off-site effects of conventional tillage which are namely organic matter loss, erosion and others (Dumanski, Peiretti, Benetis, McGarry& Pieri, 2006).

According to FAO (2007), through practicing CA, due to the layer of ground cover, a farmer can benefit by having increased organic matter (OM), increased water conservation, improvement of soil structure and rooting zone and lastly reduced erosion and nutrient loss. Bowles, (1990) stated that “Organic matter promotes aggregation of soil separates into pads, which allow for increased percolation, drainage, and water retention”. As precipitation patterns change, the links between SOM and soil moisture content will become ever more essential. Conservation practices, such as no-till, mulching and growing of cover crops may well be one of the methods used to try to increase soil organic matter (SOM), and can consequently increasing the soil’s capacity to retain moisture (Ugarte, Kwon, Andrews, &Wander, 2014). The combination of mulch, cover cropping and practicing no-till could produce the needed SOM to support and improve moisture retention and reduce soil erosion as compared to practicing no-tillage alone without mulch and/or cover crops.

From an agricultural point of view, one of the most important aspects is soil stability and the alteration of this property mainly occurs through human intervention, which causes the soil to physically degrade (Badalíkova B, 2010). Soil infiltration which influences the available soil water and loss is directly proportional to the stability of the soil structure (Tisdall and Adem 1986).

Conservation agriculture plots generally have greater water content in years with low precipitation, and generally in years of high precipitation no greater differences between CA and CT plots (McVay, Budde, Fabrizzi, Mikha, Rice, Schlegel, Peterson, Sweeney, Thompson, 2006; Thierfelder, & Wall, 2010). Similarly, Gruber, Mohring, & Claupein(2011), found slightly higher soil moisture content under no-till, especially at soil depth 60-90 cm, suggesting that the no-tillage system had greater water storage capacity. However, in a study conducted in a subtropical climate on bare silty soils by Liu, Gao, Wu, Tanveer, Wen, & Liao, (2013), found that no-till treatments reduced water-holding capacity and rather had adverse effects on soil structure.

2.4 Soil Cover and Residue Retention

Some of the methods to improve the availability and increase the amount of soil moisture or reduce deficit are employing mulch (plant materials), cover crops, no tillage and/or minimum tillage methods and tree planting, in rain fed farming settings among others methods. However, some of these methods for example mulching are scarcely practiced in most parts of Namibia itself due to lack of enough mulching material, required equipment and/or sometimes economic power by the small holder farmers.

Crop residues when left as mulch in the field, protect the soil by providing a physical barrier to soil movement, allow soil and organic matter accumulation (Mutema, Mafongoya, Nyagumbo, & Chikukura, 2013), improve some soil characteristics (Ferreroa, Obenatb,& Záratec, 2005) andenhance soil chemical properties. Crop residues as mulch in the field also lower loss of soil moisture, improve soil air circulation, develop root zone, and improve water infiltration (Mutema et al., 2013) and ultimately leading to increase in crop yield (Bationo and Mokwunye, 1991; Geiger, 1990; Dardanelli, Bachmeier, Salas, Lovera, Nunez Va´ zques, 1994).

Organic soil cover can be classified in three categories of ground cover which are 30-60 %, > 60-90 % and > 90 %; and CA requires soil cover of 30 % or more, measured soon after direct planting of crops(FAO, 2013). Past research findings recommend that thick layers of mulch are often required, occasionally ranging from 15 to 20 t/ha of mulch (Christofolleti et al., 2007).However, in semi-arid areas where smallholder depend on rain for crop production mulch application using cereal crop residues is hard as cereal residue production levels are often low (Gowing & Palmer, 2008), typically yielding on average less than 2 t/ha.

Even though mulch is known for its positive attributes, it is highly dependent on the type of plant material used. The type of plant materials used too can have negative implications on the crops and the soil, such as the introduction of weeds, pests, disease and several more (Erenstein, 2003). During the dry season in Eastern and Southern Africa, smallholders usually use crop residues as cattle feed to feed the livestock, in particular cattle. Trade-offs are often the results in areas where dry spells are long and feed alternatives are few (Giller, Witter, Corbeels, & Tittonell, 2009;Valbuena, Erenstein, Homann-Kee Tui, Abdoulaye, Claessens, Duncan, & van Wijk, 2012; Jaleta et al., 2013).This often results in inadequate quantities of vegetation cover for the soil, and causes inappropriate compensation of organic matter or plant nutrients in crop fields (FAO, 2009)

2.5Soil Moisture and Infiltration

One of the major causes of risk in Africa with regard to agriculture production is the risk of moisture stress, which is all too often, is more a result of inefficient rainfall use rather than poorly distributed rainfall *per se***.** Soil moisture stress is one of the primary limiting factors in crop production as it affects a host of major plant physiological and biochemical processes (Purcell et al., 2007).However, Jalota Khera & Chahal, (2001), acknowledged that the success of a crop depends upon the nature of the soil and the amount of moisture stored in it. The presence of dry spells, erratic rainfall in the middle of the season, and moisture loss from the soil through evaporation during the cropping season leads to crop failure.

Water infiltration which is defined as the movement of soil water from top soil to lower soil levels can also be described as the natural opposition to soil water evaporation and plays a vital role in agricultural production. When there is high rate of precipitation and low soil infiltration, water is often forced to move on the surface of the top soil, an event called run-off. It is estimated that on average 83% of the total rainfall received evaporates shortly after precipitation, whilst the remaining 17% is available as surface run-off. Of this proportion, 1-2% recharges ground water sources, 13% -14% is lost through the process of evapo-transpiration and only 2% remains to be harvested into dams. Rockström *et al*. (2001)reported from Southern and Eastern Africa that 10–25% of rainwater is lost through runoff, and another 30–50% lost through evaporation on unprotected soil surfaces rather than being taken up by plants and used for productive transpiration. In neighboring Zimbabwe, rather than being taken up by crops 30% of rainfall may be lost to runoff alone, and this may lower and/or limit crop productivity (Elwell and Stocking, 1988).

Water infiltration has been found to be highly responsive to changes in environmental factors such as precipitation, temperature, wind, humidity and changes in the physical and chemical properties of the soil. Geographical features such as the topography of the terrain and the type of soil found in the area and the soil depth are also factors that affect infiltration.

Reduced tillage practices such as ripping and sub-soiling have the potential to mitigate the effect of dry spells and moisture stress and improve soil moisture retention, which if not managed carefully all too often result in negative impact on crop productivity and/or may lead to crop failure. Ahmed and Suliman, (2010), and Al-Kaisi & Broner (2012) stated that, in most legumes, when moisture stress occurs at critical growth stages such as flowering, podding and pod/seed filling, high grain yield loss is all too often the final outcome.

With the ever present threat of climate change, the introduction of Conservation agriculture could play a big role in the improvement of the small-scale sector food security and livelihoods of the communal farmers. For instance, in the NSCA project (2012-2014) furrowing was found to enable infield water harvesting by concentrating rain water in the base of the furrow, increasing moisture by 75% (MAWF brochure). The NSCA project was funded by the United Nations Development Plan GEF Small Grants Programme, administered by the Namibia Nature Foundation (NNF) and run by NRC in Kavango Regions and more specifically the Mahahe site (45 km east of Rundu).

Tillage practices have a significant influence on the soil hydro physical properties such as bulk density (ρb) among others (Logsdon, Allmaras, Wu, Swan & Randall, 1990; Tebrügge &During 1999; Green, Ahuja, &Benjamin, 2003; Moret & Arrúe 2007b; Guedes-Filho,Blanco-Canqui, & Da Silva, 2013).It has in the past though been identified that fields controlled through CA generally have greater water content in years with low precipitation, and generally no greater differences between CA and CT plots in years with high precipitation (McVay et al. 2006).It has been similarly identified by Lafond, May, Stevenson, & Derksen, (2006); Strudley, Green, & Ascough II, (2008); Tsuji, Yamamoto, Matsuo, & Usuki,(2006), that in most cases,extensively tilled fields contain higher soil moisture during springtime than those under intensive primary tillage. As such, the conservation of soil water and nutrients requires appropriate tillage practices that conserve adequate soil moisture and improve water infiltration needed to replenish soil moisture for plant growth.

3 Materials and methods

In the following section the reader will be introduced to the study sites, the trials and their experimental layout under the project, the treatments of interest, the field management practices applied during the study period, the data collected and how the analysis was carried out.

3.1 Site description

3.1.1 Site locations

The research trials were conducted at two sites: Liselo Research Station in Zambezi Region (17.524745°S; 24.238707°E) (see Figure 1), Namibia and Mashare Irrigation Training Center in Kavango East, Namibia (17.889300°S; 20.170258°E) (see Figure 2). Two sites in the North Eastern regions of Namibia (Liselo and Mashare) were chosen based on management practices and crops grown and weather to be representative of the North and Zambezi regions in soil type and texture.

Figure 1: *Location of Liselo Research Station(LRS) in Namibia*

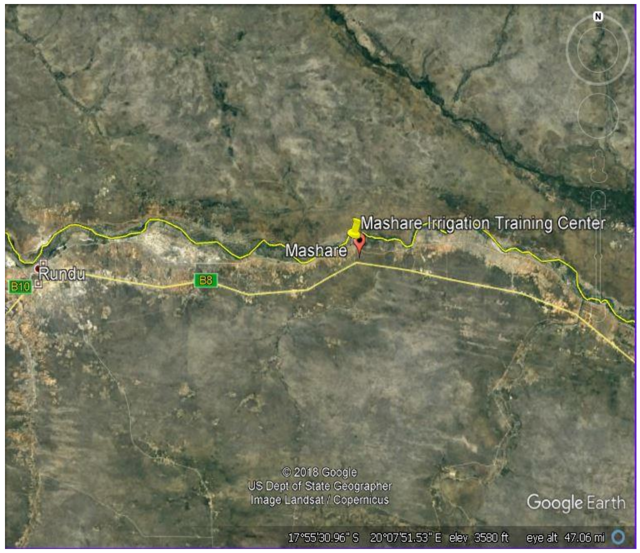


Figure 2: *Location of Mashare Irrigation Training Center*

These two sites are mainly differentiated in terms of amount of rainfall received per year, dominant soils types and their inherent fertility. The major characteristics of the sites Liselo Research Stations and Mashare Irrigation Training Center are listed in Table 1.

Figure 3: *Site Characteristics for Liselo Research Station and Mashare Irrigation Training Center*

Site	**Elevation** (m asl)	**Climate:**	**Annual Mean Temperature:**	**Annual Mean Rainfall:**	**Soil texture classes:**
Liselo Research Station	964	Hot, semi-arid	21.3°C	600-700 mm	Loamy sand to sand
Mashare Irrigation Training Center	1,050	Hot, semi-arid	22.3°C	450-650 mm	Sandy loam to loamy sand

Prior to plot establishment, the Liselo Research station had natural vegetation grown dominated by mixed subtropical woodland containing copalwood (*Guibourtia coleosperma*), *Terminalia serecea*, Zambezi teak (*baikiaea plurijuga)*, and *Acacia eriolaba* trees, shrubs and grasses. Mashare Irrigation Training Center on the other hand was used as part of the Irrigation Training Center for pearl millet production. Maize (*Zea mays* L.), Pearl millet and cowpea (*Vigna unguiculata* L. Walp.) are the principal crops at both sites, while groundnuts (*Arachis hypogaea*) and Bambara groundnuts (*Vigna subterranea*) were also important legume crops.

3.1.2 Soil fertility

Soil from both research sites were evaluated for soil fertility levels (Nitrogen, Phosphorus and Potassium), organic C, estimated percentage soil organic matter (SOM) and PH. At both study sites, the levels of nitrogen and phosphorous, Organic C, and estimated SOM were far below the suggested range for grains. Only potassium and Soil pH fell within the suggested range for grains (Figure 4).

Figure 4: *Soil nitrogen, phosphorous, potassium, organic carbon, soil organic matter, and pH levels at the two study sites*

	Average value at Liselo Research Station	**Average value at Mashare Irrigation Training Center**	**Suggested range for grains**
N (g kg^{-1}**)**	0.48	0.28	1.0– 2.0
P (g kg^{-1}**)**	<0.1	<0.1	0.2 – 0.6
K (g kg^{-1}**)**	2200	2800	1.5 – 3.0
Organic C (g kg^{-1}**)**	6.9	2.9	17 – 50
Estimated SOM (%)*	1.2	< 1	2.9 – 8.6
pH	5.3	6.1	4.9 – 6.4

Soil Cares (2017, www.soilcares.com) provided the suggested range for grains is based on soil analysis. N = nitrogen; P = phosphorous; K = potassium; C = carbon; SOM = soil organic matter. n = 24 at Mashare Research Station; n = 24 at Liselo Research Station. (Lee N.M, 2018)

* Soil organic matter estimation is based on a conversion factor of 1.72 [soil organic matter = 58% C (Pribyl, 2010)].

3.2 Experimental Design

3.2.1 Liselo Research Station (LRS) Trials

3.2.1.1 Component Trial

The Component Trial is a experiment with individual treatment associated to the individual and combination of the principles of Conservation Agriculture, namely Crop rotation, Permanent soil cover and Minimum soil disturbance in comparison to methods in Conventional agriculture.

At Liselo Research Station, the Component Trial consisted of eight (8) treatments in a Randomized Complete Block Design (RCBD) with four (4) replications with dimensions of total trial size of: 50.4m x 48m and each plot size of: 7 rows x 12m. Plots which included a maize-cowpea rotation were split into two sub-plots each for each rotational crop. Each plot had dimensions 6m x 7 rows (see Figure 5).

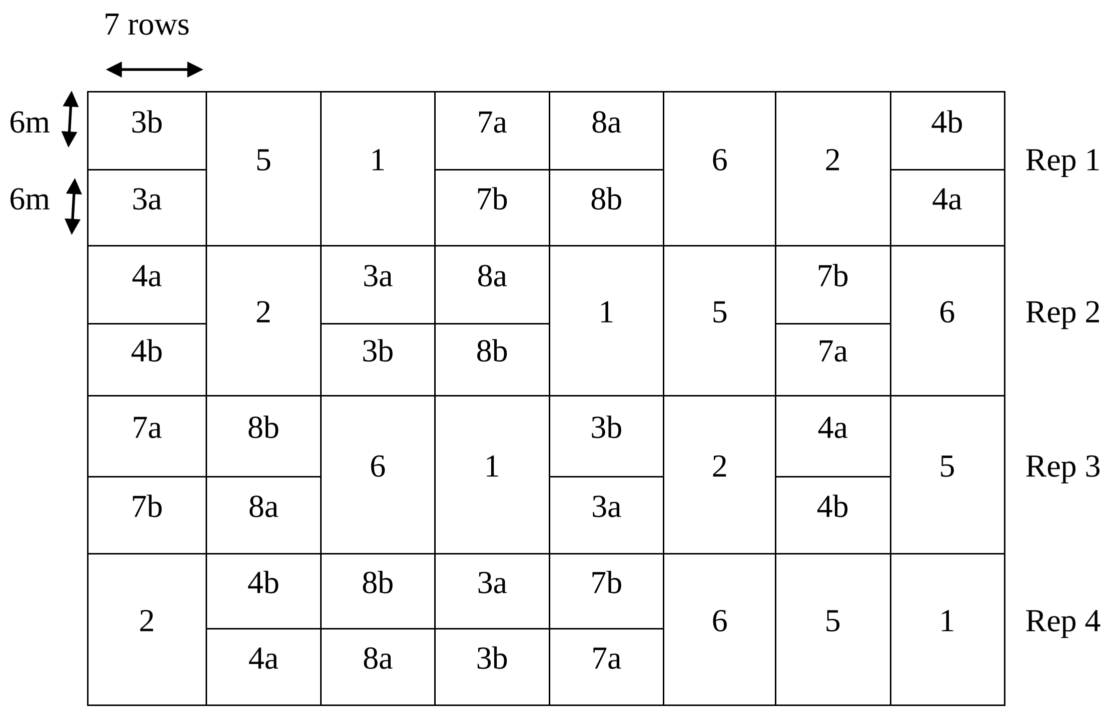


Figure 5: *Component Trial Field Design Layout at Liselo Research Station and Mashare Irrigation Training Center The conventional tillage CT treatments 1-4 plots were prepared with an animal drawn mouldboard plough, turning over the top soil within each plot. Each plot maize plot had 6 rows while cowpea plots had 8 rows following required row spacing. The CA/minimum-tillage treatments 5-8 were prepared with an animal drawn Magoye ripper, opening narrow furrows that are about 5-10 cm deep. Each maize plot had 5riplines while cowpea plots had 8 riplines following required row spacing. Treatments 2, 4, 6 and 8 had 2.5-3 t/ha of stover/grass as mulch applied at the onset of the trial and all crop residues were retained of on the soil surface in the subsequent seasons after harvesting.*

Two major treatment groups were tested, namely Conservational Agriculture (CA) group addressing the CA principle minimal soil disturbance and the other group was Conventional Tillage (CT) group. Each group consisted of four individual treatments with incorporation of (2) crop rotation and (3) permanent soil cover with crop residues or growing plants.

In summary, the treatments tested were:

- □ Conventional tillage (CT): maize was manually seeded with no residue application, and manual fertilization was done in the tilled seedbed after ploughing at shallow depth (10–15cm).
- □ Conventional tillage, mulch (CT-M); maize was manually seeded with crop residue retained, and manual fertilization was done in the tilled seedbed after ploughing at shallow depth (10–15cm).
- □ Conventional tillage, rotation (CT-R); maize and cowpea were manually seeded on respective portions of the plot with residues removed, manual fertilization was done in the tilled seedbed after ploughing at shallow depth (10–15cm).Annual maize-cowpea crop rotation was done from season one to season two.
- □ Conventional tillage, mulch and rotation (CT-MR); maize and cowpea were manual seeded on respective portions of the plot with crop residue retained, manual fertilization was done in the tilled seedbed after ploughing at shallow depth (10–15cm).Annual maize-cowpea crop rotation was done from season one to season two.
- □ Minimum tillage (MT): maize was manually seeded with no residue application, and manual fertilization was done in riplines prepared with a Magoye ripper.
- □ Minimum tillage, mulch (MT-M): maize was manually seeded with crop residue retained, and manual fertilization was done in riplines prepared with a Magoye ripper.
- □ Minimum tillage, rotation (MT-R): maize and cowpea were manually seeded on respective portions of the plot with residues removed, manual fertilization was

done in riplines prepared with a Magoye. Annual maize-cowpea crop rotation was done from season one to season two.

- Minimum tillage, mulch and rotation (MT-MR): maize and cowpea were manual seeded on respective portions of the plot with crop residue retained, manual fertilization was done in riplines prepared with a Magoye ripper. Annual maize-cowpea crop rotation was done from season one to season two.

At LRS, the commercial hybrid maize variety Zamseed 606 and Commercial cowpea variety BIRA were seeded on November 24, 2016in the first season 2016/17.Basal fertilizer at a rate of 150 kg/ ha NPK (2:3:2) was applied to all treatments (only for maize)at seeding and placed next to the plant station. 150 kg ha^{-1}Urea was top dressed on all treatments as a split application on January 23, 2017 and February 06, 2017 in the first season.

In the second season 2017/18the experiment was repeated, with seeding on November 26, 2017. Top dressing was applied on January 15, 2018 and January 18, 2018 in the second season.

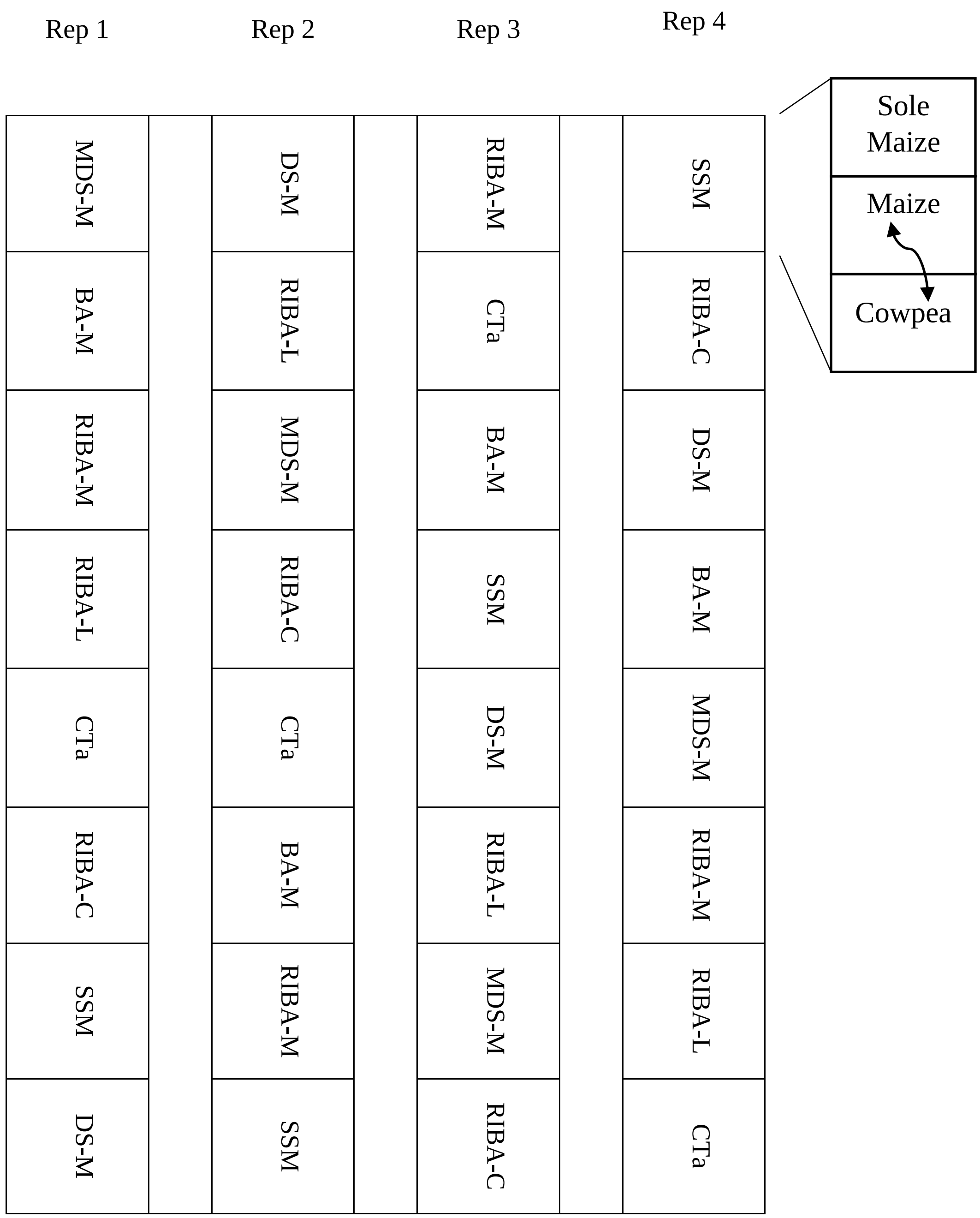
Figure 6: *Component Trial Mulched plots*

Figure 7: *Component Trial Un-mulched plots*

3.2.1.2 The Systems Trial

At LRS, the Systems Trial consisted of eight tillage treatments in a randomized complete block design with four replications with dimensions of total trial size of: 49mx160m (7840m^2) and each plot size of: 20mx10m (200m^2) (see Figure 8).

Six CA tillage treatments were compared to two conventional farmers’ practices treatments, seeded in tilled land with no crop residue retention. Maize was planted as a continuous crop on two-thirds of each plot with the other one-third of the plots planted with continuous sole cowpea. The one-third plot of maize neighboring cowpea eventually rotated with the one-third cowpea section in the second season.



CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick.

Figure 8: *CA Systems Trial Field Design Layout*

The treatments tested were:

- □ Conventional ploughing (mouldboard, animal traction) (**CTa**): maize and cowpea were manually seeding on the respective portions of the plot with all residue removed, and manual fertilization was done in the tilled seedbed after ploughing at shallow depth (10–15cm).
- □ Ripping with a Baufi animal traction ripper – Cowpea intercrop (**RIBT-C**): maize and cowpea were manual seeded on the respective portions of the plot with residues retained, and manual fertilization was done to all maize planting stations and crops in the riplines. After 4 week cowpea was manually seeded between rows of maize as an intercrop.
- □ Ripping with a Baufi animal traction ripper - Lablab intercrop (**RIBT-L**): maize and cowpea were manual seeded on the respective portions of the plot with residues retained, and manual fertilization was done to all maize planting stations and crops in the riplines prepared with a baufi ripper. After 4 week lablab was manually seeded between rows of maize as an intercrop.
- □ Ripping with a Baufi animal traction ripper (**RIBT**): maize and cowpea were manual seeded on the respective portions of the plot with residues retained, and manual fertilization was done to all maize planting stations and crops in the riplines prepared with a baufi ripper.
- □ Sub-soiling with a Magoye ripper (**SSM**): maize and cowpea were manual seeded on the respective portions of the plot with residues retained, and manual fertilization was done to all maize planting stations and crops in the riplines prepared with a magoye ripper.
- □ Direct seeding with an animal traction direct seeder (**DS-M**): maize and cowpea were seeded and fertilized on respective portions of the plot carried out with the Fitarelli animal direct seeder. Residues were manually retained on the plot.
- □ Basin Planting Dug with a hand hoe (**BA-D**): maize and cowpea were manually seeded on respective portions of the plot in basins (15cm x 15cm x 15cm) which were manually dug with hoes and manually seeded and fertilized at the onset of rains.

- Manual direct seeding with a Dibble stick (**MDS-D**): maize and cowpea were manually seeded on respective portions of the plot with residue retained, and manual fertilization was done in pits prepared with a Dibble stick.

Figure 9: *A System plot ripped with an animal drawn Magoye Ripper for the treatment SSM at LRS*

Figure 10: *A System Plot prepared with an animal drawn Mouldboard Plough For the treatment CTa at LRS*

The commercial hybrid maize variety Zamseed 606 and the commercial cowpea variety BIRA were seeded on 14-16 December 2016, during the first season and seeded on December 7, 2017, during the second season. Basal fertilizer at a rate of 150 kg /ha NPK (2:3:2) was applied to all treatments at seeding and placed next to the plant station except when seeded with the animal traction direct seeder, where fertilizer was dribbled in the row by the seeder for maize. Top-dressing with 150 kg ha^{-1}Urea was applied to all maize plants of all treatments as a split application on January 23, 2017 and February 06, 2017 for the first season and on January 15, 2018 and February 15, 2018 in the second season.

Figure 11: Systems Maize and cowpea at LRS, 12weeks after seeding in the first season

3.2.2 Mashare Irrigation Training Center (MITC) Trials

3.2.2 Component Trial

At MITC, the Component Trial consisted of the same eight treatments as in LRS with Pearl millet as the cereal crop seeded at MIC. The same randomized complete block design layout with four replications with dimensions of total trial size of: 50.4m x 48m and each plot size of: 7 rows x 12m. Plots which included a rotation were split into two sub-plots each 6m x 7 rows which was used in LRS was also applied at MITC(see Figure 5).

Commercial pearl millet variety OKASHANA2 and Commercial cowpea variety BIRA were seeded on Nov 24 and 27 in 2016,during the season 2016/17and the same varieties were seeded on Nov 18 2017 in the second season of 2017/18.Basal fertilizer at a rate of 150 kg ha^{-1}NPK (2:3:2) was applied to all millet plants in all treatments at seeding and placed next to the plant station. 150 kg ha^{-1}urea was similarly top dressed on all treatments as a split application.

Figure 12: *Component Trial at MITC in 2017 after harvesting pearl millet and cowpea grains of the first season. Pearl millet crop residues were placed on the ground to provide ground cover immediately after harvesting.*

3.3Seeding and Weed Management

At LRS maize was manually seeded in rows spaced 90 cm apart and 35 cm between planting holes with two seeds planted per hole later then thinned to 1 plant to reach a target population of 31,746 plants/ha. The direct seeder used in the system trial was calibrated to give the same population with maize seeds spaced approximately every 25 cm in the row.

At MITC using about 5 kg of seed per hectare, pearl millet was manually seeded in rows spaced 75 cm apart, dribbled seed and thinned to one plant every 25cm to reach a target population of 53,333 plants/ha. The direct seeder used in the system trial was calibrated to give the same population with pearl millet seeds dropped approximately every 25 cm in the row.

At LRS cowpea was manually seeded in rows spaced 45 cm apart and 25 cm between planting holes with two seeds per hole then thinned to 1. The direct seeder used in the system trial was calibrated to give the same population with seeds dropped approximately every 25 cm in the row. At MITC cowpea was manually seeded in rows spaced 37.5 cm apart and 30 cm between planting holes with two seeds per hole then thinned to 1 plant.

Weed control was achieved by scratching the top soil using a regular hand-weeding when seen as necessary.

At harvest, cobs were removed from the plots and the remaining crop residues (Stover) retained on the respective CA and CT treatments. Stover yields ranged from 3.2 to 5.2 t ha^{-1}. Approximately 80kg of mulch was applied on each plot of 10m *20m for the Systems Trial and 15kg on each plot of 6m*6m for the Component Trial.

3.4 Field methods and data collected

3.4.1 Soil moisture content

For the soil moisture data recording, access tubes were installed in all treatments at LRS and MITC. Three access tubes were installed per plot in 4 replicates in the Systems Trial and one access tube was installed per plot in 4 replicates in the Component Trial). Soil moisture content was measured to a depth of 1 m with a capacitance probe (PR-2 probes, Delta-T Devices Ltd., UK) once a week during the dry season and twice per week during the cropping season. Data from the 0–10, 10–20, 20–30, 30–40 and 40–60 cm horizons are reported in this paper. Mean soil moisture content in mm for each soil depth layer over the cropping season was determined, mean soil moisture content (mm) in the 0-30cm and 0-60 cm soil depths were calculated and are presented in this paper.

3.4.2 Water infiltration and runoff

In both cropping seasons 2016/2017 and 2017/2018, measurements of infiltration was carried out in the Systems Trial on the 3 principle treatments at LRS: the Conventional Tillage (CTa), the Magoye ripping treatment (SSM) and Dibble stick (MDS-D), using a small rainfall simulator described by Amée´ zquita et al. (1999) and Thierfelder et al. (2005). Simulated rainfall of a known intensity of approximately 95 mm h^{-1} was applied to an area of 36 cm * 44 cm for an hour and runoff measured from an area of 32.5 cm * 40 cm (0.13 m^2). Run-off was recorded every 5 minutes and totaled as total run-off. The difference between water applied and runoff was recorded as Total infiltration (%).Simulated rainfall measurements were done only at LRS from the month of January to February of each cropping season when the maize crop was at, or just before, the tasseling stage. Simulated rainfall measurements were done on one spot in each plot, replicated 3 times over the two months each season mainly in the inter-row space, when the soil was at or close to field capacity.

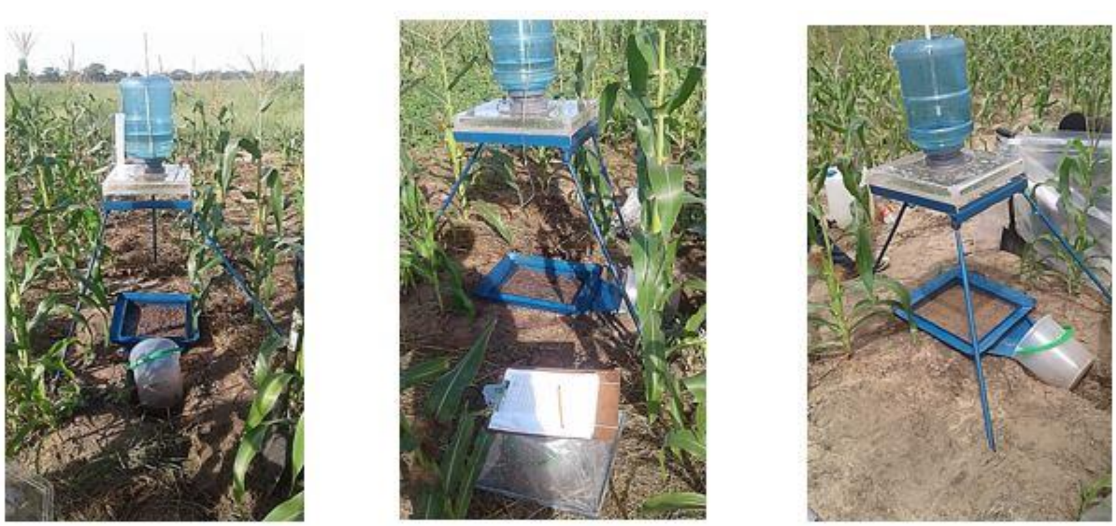


Figure 13: *Rainfall Simulator set up in between maize rows, used to do rainfall simulation experiment (Infiltration and Run-off) at LRS*

3.4.3 Harvest data

At both sites the maize, pearl millet and cowpea were harvested at physiological maturity and total above-ground biomass and grain yield determined on each plot. A sub-sample of 20 cobs was used as a sample to determine maize grain moisture. While for pearl millet and cowpea samples of 500g grain from each plot were used to determine grain moisture. After final harvesting at both sites, the cowpeas were left growing until they eventually died off due to drought.

***Figure 14**: Yield samples, cobs and residue in paper bags (Maize and Cowpea) air and sun drying in Katima Mulilo*

3.5 Statistical methods

Linear model, Analysis of variance (ANOVA) using Statistical analysis software 'Statistix 9' for personal computers was used to test for normality and test for any significant difference in final infiltration, runoff, moisture content and grain yield among all treatments. Analysis of variance was used to test for interaction between tillage, rotation and mulching, and the main effects of tillage, rotation and mulching on soil moisture and grain yield. Probability levels of 0.05 were used to determine the level of significance among the means. LSD All-Pair wise Comparisons Test was used to compare soil moisture and grain yield of for treatment effect.

4 Results

4.1 Site conditions

4.1.1 Rainfall Data records of the two Sites

Rainfall at both LRS and MITC for the 2016/17cropping season was erratic with a short rainy season especially at LRS (Figure 3). LRS recorded total seasonal rainfall of 499.9 mm and MITC recorded a high total seasonal rainfall of 715.2 mm for the first cropping season 2016/17.A dry spell of two weeks and six days was experienced during the first season from February 2, 2017 to February 22, 2017at LRS (see Figure 3).Rainfall at both LRS and MITC for the 2017/18 cropping season was erratic with especially low rain incidences at the early stages of the season (Figure 3). Seasonal total rainfall recorded at LRS and MITC was 521 mm and 530.4 mm respectively for the 2017/18cropping season. In January 2018, LRS received 44 mm, while 233 mm of total rain fell in February 2018. Rainfall amount of 1.3 mm at MITC, from December 31, 2017 to January 21, 2018, was insufficient for crop growth and development. Rainfall eventually increased as the season advanced, particularly in March, during which the site received 214 mm of the total 521mm (see Figure 15).

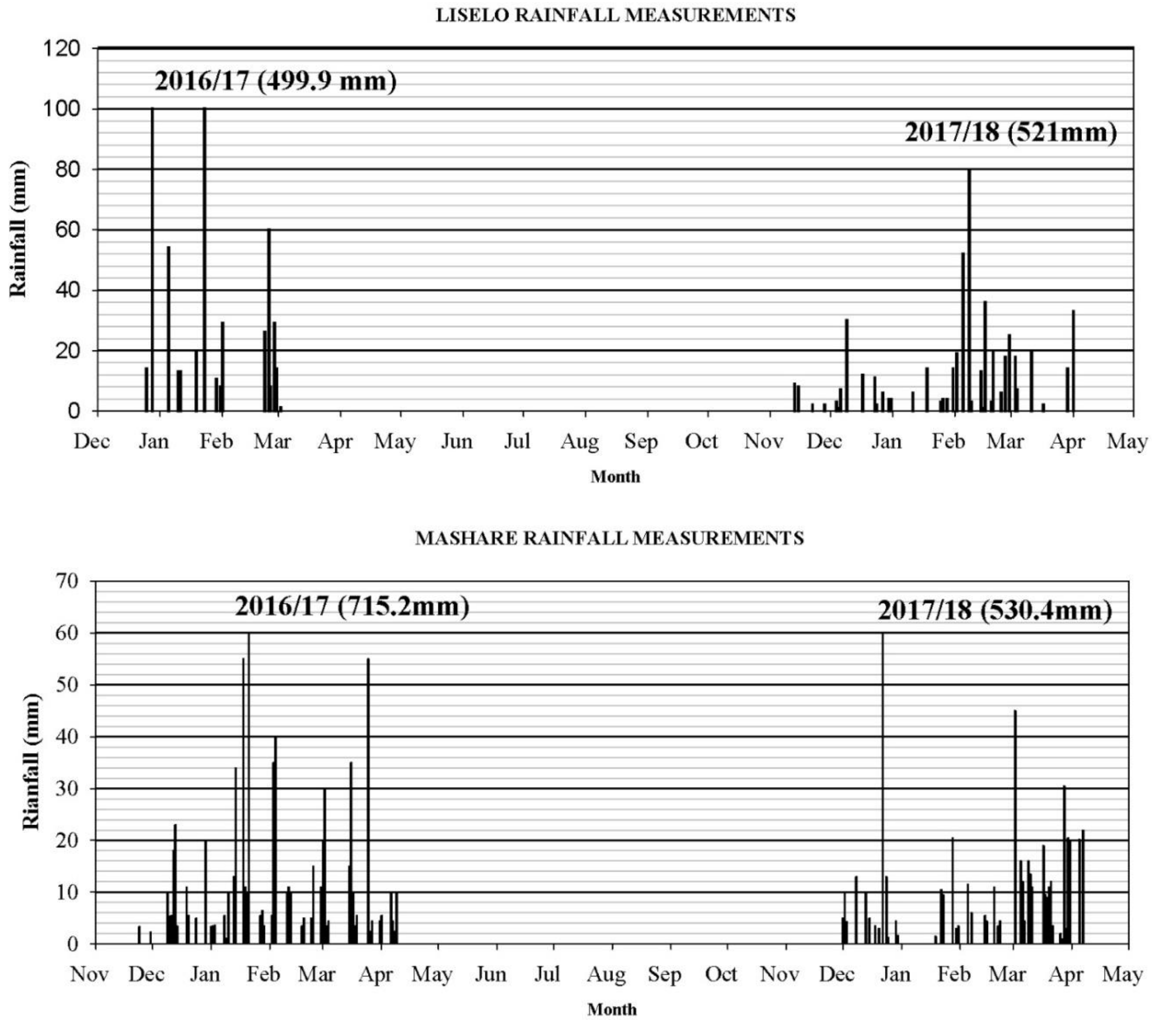


Figure 15: *Rainfall Measurements at LRS and MITC for the first and second seasons*

4.2 Total infiltration and total run-off of the Systems Trial

There were no statistically significant differences between the effects of tillage treatments on total water infiltration and run-off during simulated rainfall experiments at LRS in both cropping seasons (see Figure 16).

Total infiltration at LRS was very high (>91.3%) regardless of treatment, this could be accredited to the fact that the site is predominantly sandy.

TREATMENT	INFILTRATION (%)		RUN-OFF (%)	
	2016/17	2017/18	2016/17	2017/18
CTa	91.3	94.5	8.7	5.5
SSM	96.1	99.0	3.9	1.0
MDS-D	95.2	97.9	4.8	2.1

CTa = Conventional Ploughing (mouldboard, animal traction), SSM = Sub-soiling with a Magoye ripper, MDS-D = Manual direct seeding with a Dibble stick. Different letters indicate significant differences between least square means at α = 0.05and are not comparable across seasons

Figure 16: *Total infiltration and total run-off of the Systems Trial at LRS*

4.3 Soil moisture results of the Systems Trial

4.3.1 Soil Moisture of the Systems Trial in the 0-30and 0-60 cm soil depth throughout the study period,

Significant differences were observed among different tillage systems on average soil moisture in the 0-30 and 0-60 cm soil depths over the two cropping seasons($P<0.05$) (see Figure 17).

SSM plots had the highest average soil moisture content in the 0-30cm soil depth with a soil moisture content of 14.9mm. MDS-M and CTa plots were found to be insignificantly different from each other with soil moisture averages of 14.1mm and 14.4mm, respectively (see Figure 17). This happened despite differences in their level of soil disturbance. Moreover, MDS-M plots were mulched while CTa plots were not mulched.

TREATMENT	Soil moisture content (mm)	
	0-30 cm Soil Depth	0-60 cm Soil Depth
CTa	14.4 AB	39.3 B
RIBT-C	12.1 D	35.4 E
RIBT-L	13.8 B	37.8 C
RIBT	12.9 D	36.4 D
SSM	14.9 A	40.5 A
DS-M	13.6 BC	38.7 BC
BA-M	13.6 BC	38.6 BC
MDS-D	14.1 AB	39.3 B
P	0.0000	0.0000

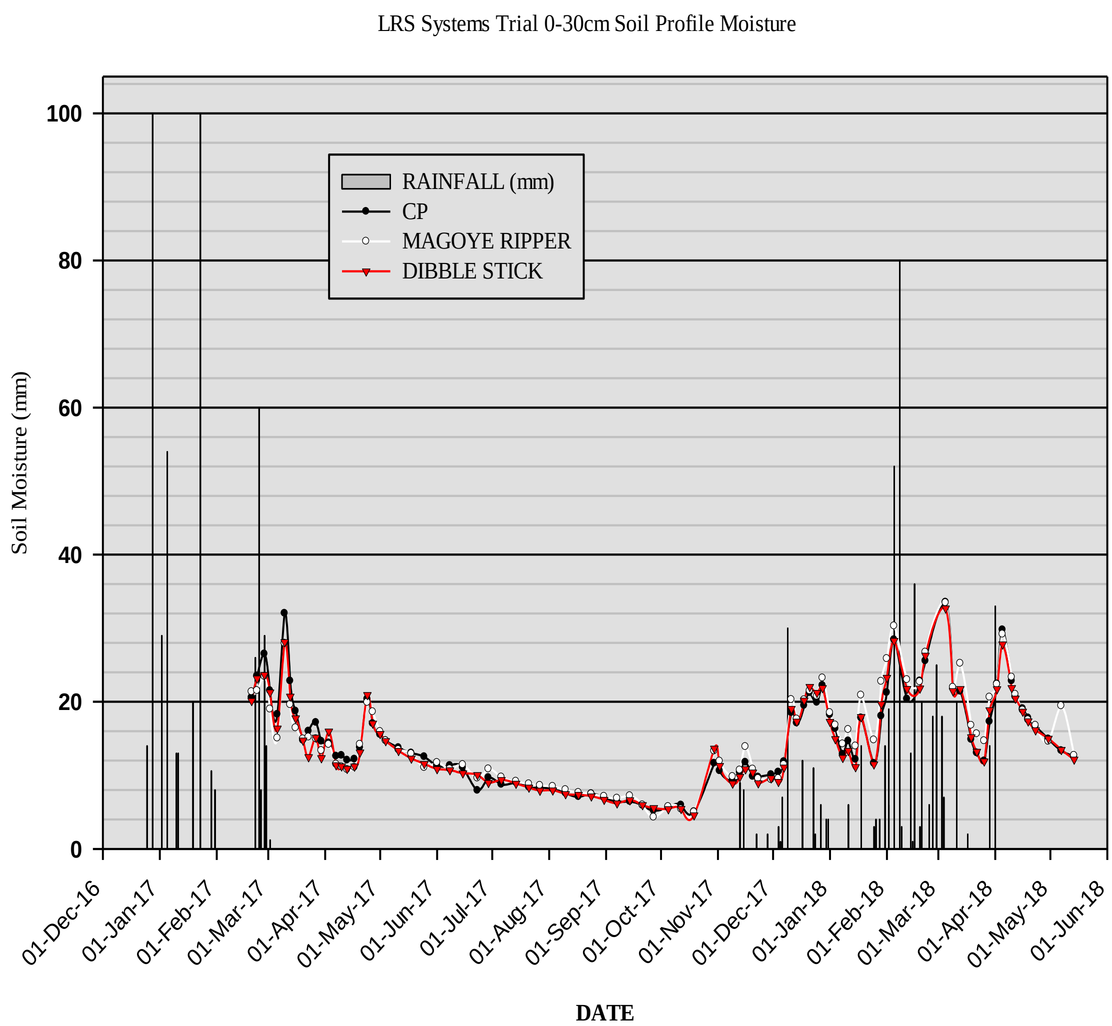
CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick. Different letters indicate groups (A, B, etc.) in which the means are not significantly different from one another and are not comparable across seasons.

Figure 17: *Soil Moisture of the Systems Trial in the 0-30and 0-60 cm soil depth throughout the study period at LRS*

SSM, MDS-D and CTa treatment plots had very close readings of soil moisture content in the 0-30cm soil depth, while occasionally very similar. CTa plots appeared to have higher soil moisture content in the first season after installation of the moisture tubes. At the onset of the dry season starting in the month of May some changes were detected.

SSM plots appeared to have the highest soil moisture content during this period, with MDS-M and CTa plots having similar levels. Mulch applied to the SSM and MDS-M plots did not appear to improve conservation of moisture. Thus, SSM and MDS-M had similar soil moisture content with CTa throughout the first season. During the second season's rain fed months, from November to April, SSM maintained the lead with MDS-M and CTa frequently switching places, second and last (see Figure 18).

Peak soil moisture readings in the 0-30 cm soil depth of SSM and MDS-D were recorded on the 10^{th} of March 2017 in the second season. Peak soil moisture reading of 33.5 mm was recorded in the CTa plots, while 33.4 mm and 33.7 mm were the readings in the SSM and MDS-M plots, respectively (see Figure 18).



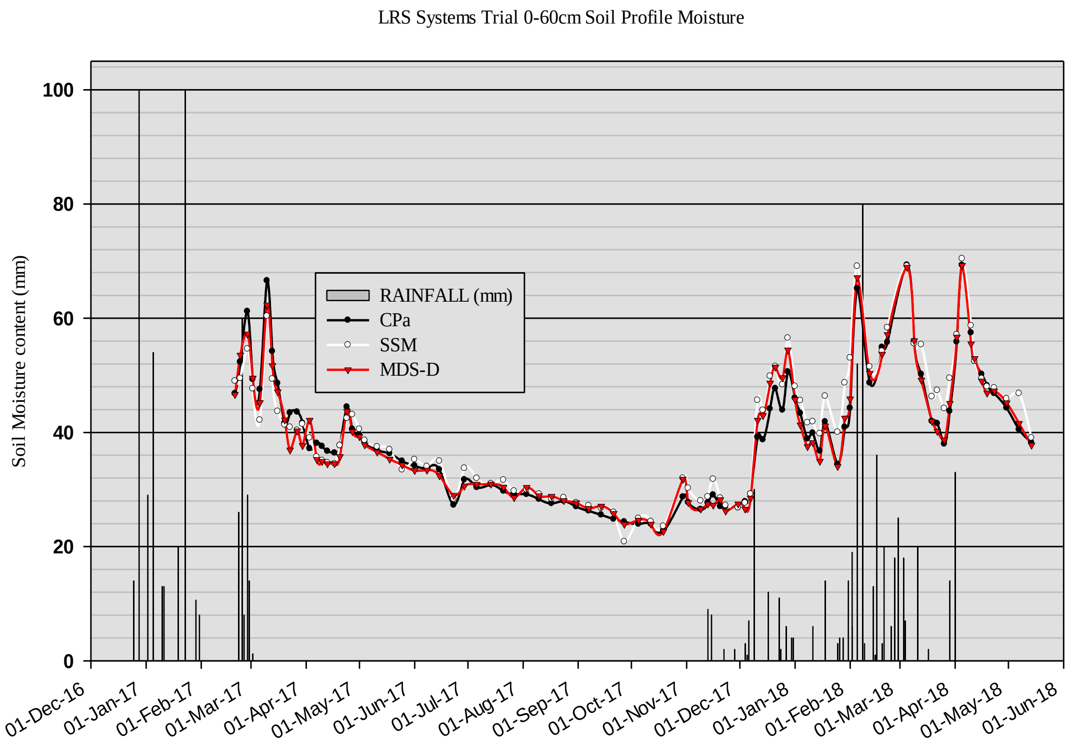
CTa = Conventional ploughing (mouldboard, animal traction), SSM = Sub-soiling with a Magoye ripper, MDS-D = Manual direct seeding with a Dibble stick.

Figure 18: *Treatment soil moisture content comparison over the study period for the CA Systems Trial in the 0-30cm soil depth at LRS*

Similar to the 0-30 cm soil depth, in the 0-60 cm soil depth under different till methods (SSM, CTa and MDS-M) there were moisture differences over the two years at LRS. SSM plots had the highest average soil moisture content (40.5 mm). MDS-M and CTa plots were insignificantly different from each. Their averages were 39.3 mm each, though MDS-M plots were mulched while CTa plots were not mulched (see Figure17).

SSM, MDS-D and CTa plots had very close soil moisture readings in the 0-60 cm soil depth, sometimes almost the same throughout the study period. In the first season, after installation of the moisture tubes, CTa plots appeared to have higher soil moisture content in the 0-60cm soil depth. SSM plots appeared to have the highest soil moisture content, with MDS-M plots in close second and CTa with the least soil moisture content in the 0-60cm soil depth over the dry season. SSM maintained the lead in soil moisture content with MDS-M and CTa frequently switching places over months November to April. CTa had soil moisture readings close to mulched SSM and MDS-M plots (see Figure 19).

Unlike in the 0-30cm soil depth, peak soil moisture readings in the 0-60 cm soil depth were recorded on different days. CTa ranked highest with a peak reading of 66.6 mm in the first season. Peak soil moisture readings were recorded in the SSM and MDS-M plots during the second season (see Figure 19). Highest moisture readings in the CTa plots were recorded on the 10thof March 2017. Peak soil moisture content reading of 69.3 mm was recorded in the SSM plots on February 5, 2018, in the second season. Two weeks after peak readings in the SSM plots, on April, 5 2018, a reading of 69.3 was recorded in the MDS-D plots.(see Figure 19).



CTa = Conventional ploughing (mouldboard, animal traction), SSM = Sub-soiling with a Magoye ripper, MDS-D = Manual direct seeding with a Dibble stick.

Figure 19: *Treatment soil moisture content comparison over the study period for the CA Systems Trial in the 0-60 cm soil depth at LRS*

4.3.2 Soil moisture of the Systems Trial in the 0-30 and 0-60 cm soil depth during the cropping seasons,

There were no significant differences observed on the effect of tillage systems on average soil moisture in the 0-30 cm soil depth in the first season while statistically significant differences were observed during the second season (P=0.000) and (see Figure 20).

It appeared conventional tillage stored similar or more moisture when compared to all other treatments except SSM. Ripping with Baufi ripper stored the least moisture, especially where cowpea was grown (see Figures 19, 20 and 21).

TREATMENT	**0-30 cm Soil Depth Soil moisture content (mm)**	
	2016/17	**2017/18**
CTa	17.8	18.2 B
RIBT-C	15.1	15.6 C
RIBT-L	16.5	17.8 B
RIBT	14.1	17.8 B
SSM	16.8	19.8 A
DS-M	15.0	18.3 B
BA-M	14.6	18.7 B
MDS-D	16.9	18.1 B
P	0.193	0.0000

CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick. Different letters indicate groups (A, B, etc.) in which the means are not significantly different from one another and are not comparable across seasons.

Figure 20: *Soil moisture of the Systems Trial in the 0-30 cm soil depth during the cropping seasons,*

Soil moisture content, in the 0-30 cm soil depth was higher in the second (15.6 - 19.8 mm)than in the first season (14.6 - 17.8 mm). During the second cropping season, SSM had the highest soil moisture content in the 0-30cm soil depth at least 1.6 mm higher than the other treatments (19.8 mm). MDS-M and CTa were insignificantly different from each other with moisture reading of 18.1 mm and 18.2 mm, respectively. (see Figure 20).

There were significant differences on the effect of tillage systems on average soil moisture in the 0-60 cm soil depth in both seasons ($P<0.05$) (see Figure 21).

Similar to readings in the 0-30 cm soil depth, soil moisture content in the 0-60 cm soil depth was higher in the second season, ranging from 42.6 –50.5 mm while in the first season it ranged from 40.6–44.4 mm. In first season CTa had the highest soil moisture content (44.4 mm), followed by MDS-M (43.2 mm) and SSM (42.9 mm). SSM had highest soil moisture content in the 0-60 cm soil depth, a reading of50.5mm. MDS-M and CTa were insignificantly different from each other with moisture reading of 47.8 mm and 47.2 mm, respectively(see Figure21).

TREATMENT	0-60 cm Soil Depth Soil moisture content (mm)	
	2016/17	**2017/18**
CTa	44.4 A	47.2 B
RIBT-C	40.6 CD	42.6 D
RIBT-L	41.9 D	46.2 BC
RIBT	40.6 D	45.1 C
SSM	42.9 BC	50.5 A
DS-M	43.3 AB	47.5 B
BA-M	42.7 BC	47.8 B
MDS-D	43.2 ABC	47.8 B
P	0.0000	0.0000

CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick. Different letters indicate groups (A, B, etc.) in which the means are not significantly different from one another and are not comparable across seasons.

Figure 21: *Soil Moisture of the Systems Trial in the 0-60 cm soil depth during the cropping seasons,*

4.4Soil moisture of the Component Trial

4.4.1 Soil moisture of the Component Trial in the 0-30and 0-60 cm soil depths at LRS and MITC throughout the study period

Significant differences were observed between the effect of tillage systems and CA principles on soil moisture content in the 0-30 and 0-60 cm soil depths at both sites ($p<0.05$) (see Figure 22).

Average soil moisture content for the 0-30cm soil depth ranged from 13.1mm to 14.5mm, and 35.1mm to 44mmat LRS and MITC, respectively. Average soil moisture content for the 0-30cm soil depth at MITC was three to about four times that of LRS.

At LRS minimum tillage treatments; namely, MT-M, MT and MT-R had higher soil moisture contents in the 0-30cm soil depth than CT. While at MITC, only MT-M and MTR had higher soil moisture content in the 0-30 cm soil depth than CT. MT-M had the highest average soil moisture content readings in the 0 - 30 cm soil depth at both LRS and MITC (14.5 mm and 44mm). MT (14.5 mm) and MT-R (42.9 mm) had the second highest average soil moisture readings in the 0 – 30 cm soil depth at LRS and MITC, respectively. CT (13.7mm) at MITC it was among lowest in soil moisture content readings, insignificant from MT-R (14mm). While, at LRS CT had the third highest soil moisture content readings in the 0-30cm soil depth(41.5mm) (see Figure 22).

TREATMENT	Average Soil moisture Content MITC		LRS	
	0-30cmSoil Depth	0-60cmSoil Depth	0-30cmSoil Depth	0-60cmSoil Depth
CT	41.5 B	117.8 C	13.7 BC	36.1 D
CT-M	41.3 BC	110.0 D	14.0 BC	37.2 BC
CT-R	35.1 E	106.8 E	13.1 D	35.1 E
CT-MR	37.3 D	109.9 D	14.1 AB	36.9 CD
MT	40.1 C	121.7 B	14.4 A	37.7 B
MT-M	44.0 A	134.5 A	14.5 A	39.8 A
MT-R	42.9 A	120.2 BC	14.0 BC	36.9 BCD
MT-MR	40.8 BC	117.6 C	13.5 CD	34.1 F
P	0.0000	0.0000	0.0000	0.0000

CT = Conventional Tillage, CT-M = Conventional Tillage-Mulch, CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. There are groups (A, B, etc.) in which the means are not significantly different from one another. And are not comparable sites and depths

Figure 22: *Soil moisture of the Component Trial in the 0-30 and 0-60 cm soil depths at LRS and MITC*

Throughout the study period, MT-M had the highest soil moisture content in the 0-30 cm soil depth. Its highest soil moisture content readings of 76.4 mm and 34 mm were recorded on 01.01.18 and 10.03.17 at MITC and LRS, respectively. Between the months of October to March of both seasons, soil moisture content in the 0-30 cm soil depth for all treatments was very close to one another especially after rainfall events. CT and MT-MR were the two least soil water storing treatments throughout most of the study period at LRS. Differences between treatments in soil moisture content in the 0-30 cm soil depth were not clear during the dry season at LRS but clearer at MITC(see Figure 17 and 21). MT-M was clearly the best treatment at MITC, distinctly higher than the rest.

CT in LRS had soil moisture content readings similar to the rest of the treatments at LRS, whilst at MITC, CT had the second highest soil moisture content in the 0-30cm soil depth over the first cropping season. Over the dry season, CT dropped to least water storing, and maintained that status into the second season. During most of the study period at LRS, MT-MR had the lowest soil moisture content in the 0-30cm soil depth period. At MITC, MT-MR was the second least water storing treatment with occasional drops to least water storing, especially after the end of the rains of the first season (see Figure17 and 21).

Average soil moisture content in the0-60cm soil depth ranged from 34.1 to 39.9mm and 106.8 to 134.5mmat LRS and MITC, respectively. Minimum tillage treatments in general were found to have higher soil moisture content in the 0-60cm deep soil depths than CT treatments at both sites. MT-M in both sites had the highest average soil moisture content in the 0-60 cm soil depths with readings of 134.5mm and 39.9mm at MITC and LRS, respectively. MT followed closely in second with readings of 121.7mm (MITC) and 37.7mm (LRS).CT (117.8mm) at MITC ranked fourth with regards to soil moisture content readings, insignificantly different from MT-MR (117.6mm). While in LRS,CT was found to have the second least soil moisture content readings (36.1mm) (see Figure 22).

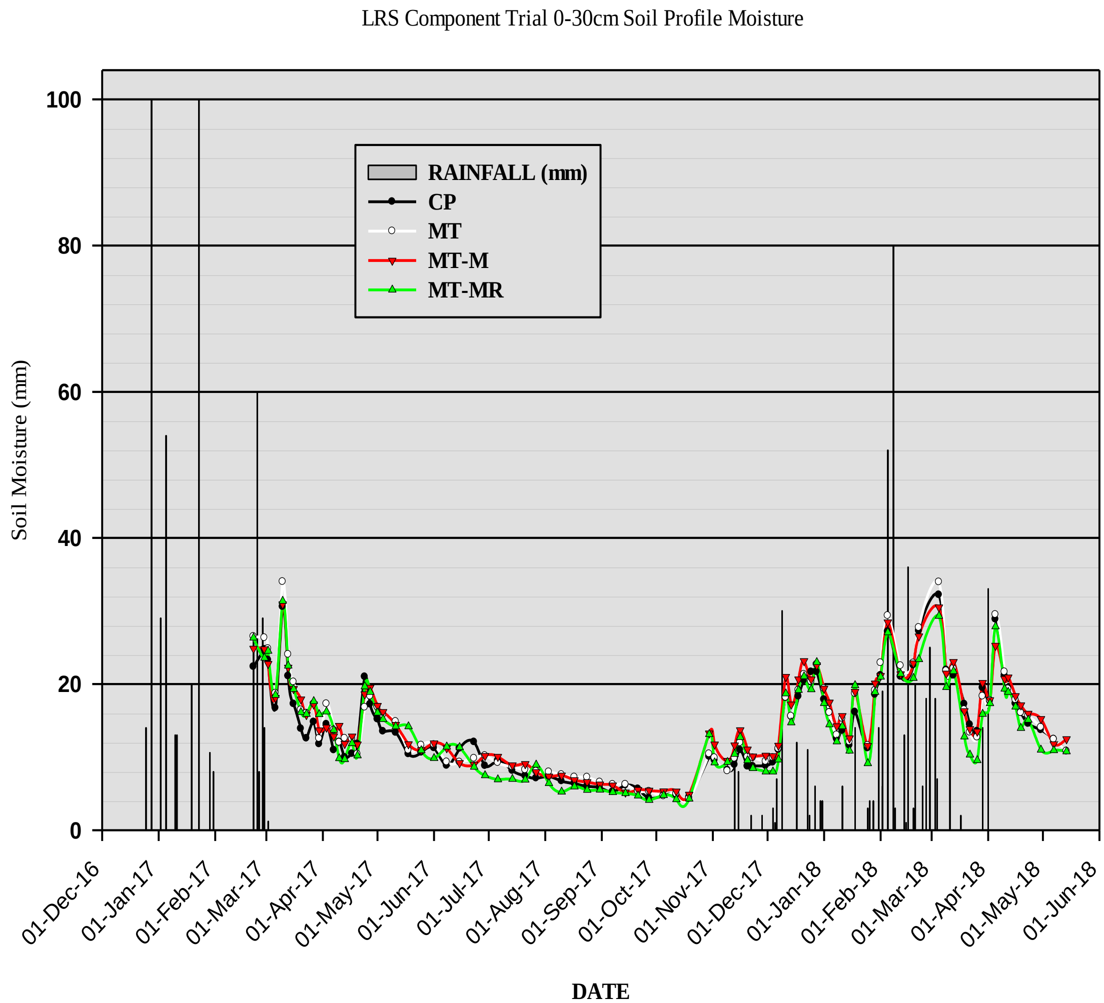


Figure 23: *Seasonal Soil Moisture content comparison for Treatments in the 0-30cm soil depth of the Component Trial at LRSCT = Conventional Tillage, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation*

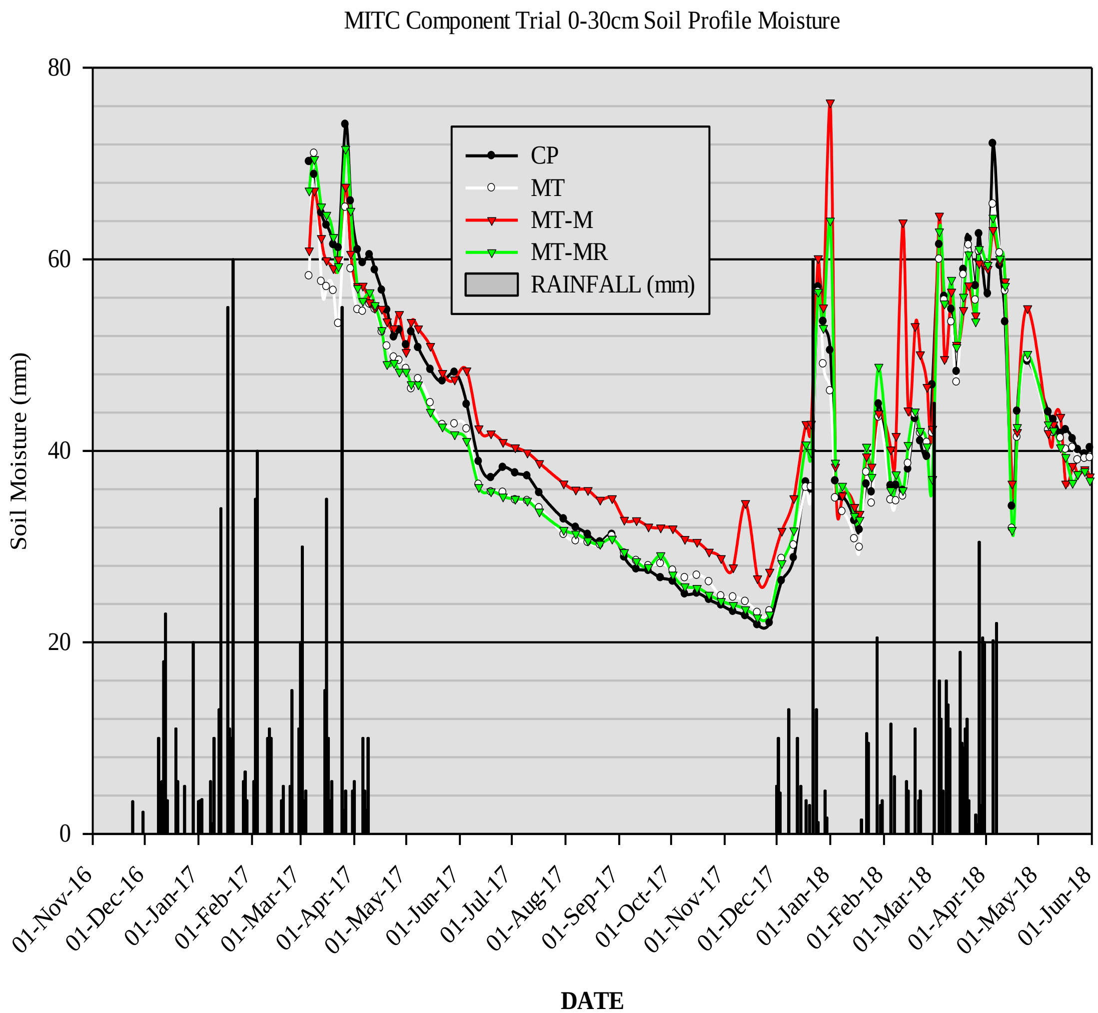
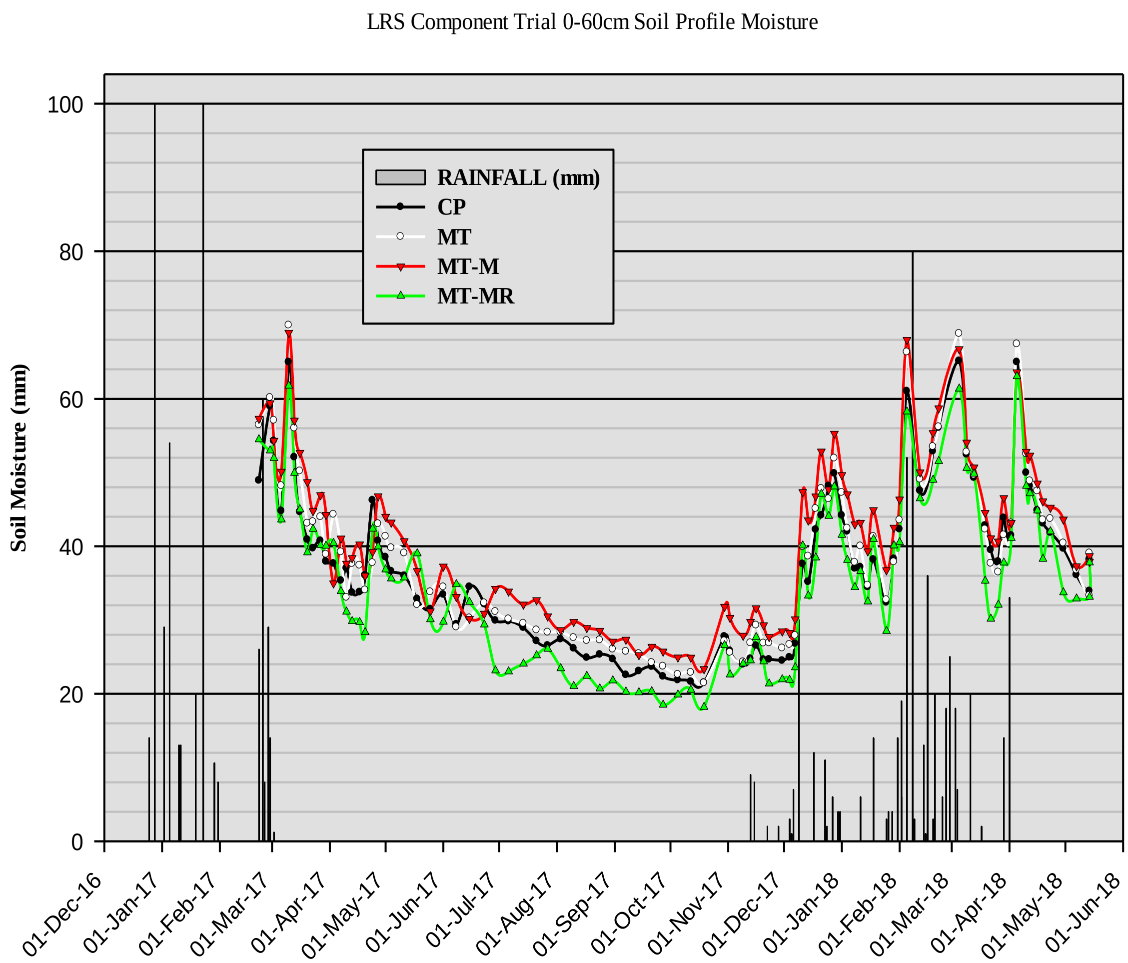


Figure 24: *Seasonal Soil Moisture content comparison for Treatments in the 0-30cm soil depth of the Component Trial at MITCCT = Conventional Tillage, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation*

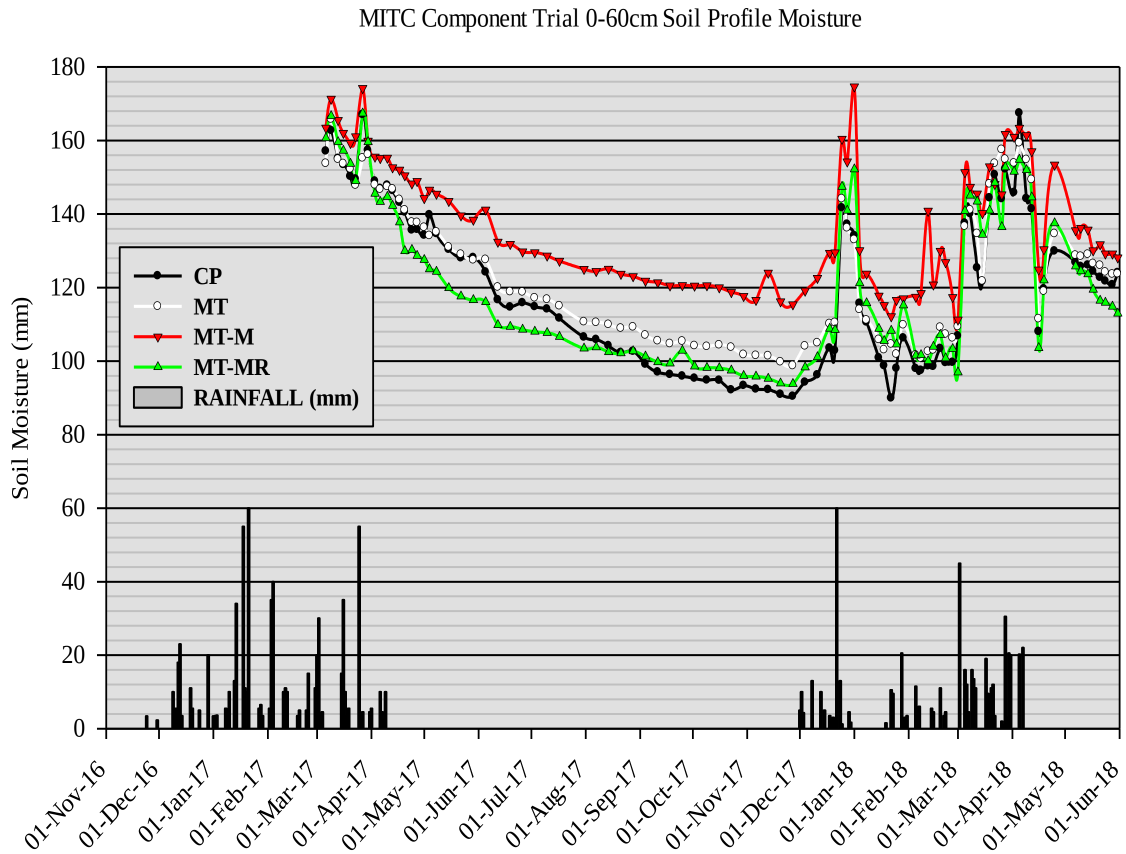
MT-M throughout the study period had the highest soil moisture content in the 0-60 cm soil depth, with a peak reading of 174.7 mm recorded on February, 1 2018 at MITC. At LRS the highest soil moisture content reading of MT-M (69.0 mm)was recorded on March 10, 2017. MT, had the second highest soil moisture content at throughout the study period at both sites. MT-MR was the least soil water storing treatment throughout the study period at LRS. Specifically, MT-MR was the least water storing over the first cropping season and halfway into the dry season. MT-M and MT-MR were clearly having the highest soil moisture content in the 0- 60 cm soil depth at MITC, especially during the dry season (see Figure 23 and 24).

CT in LRS had only higher soil moisture content in the 0-60 cm soil depth than MT-MR. Whilst in MITC, CT had the third lowest soil moisture content readings over the first cropping season. In the subsequent season it dropped to least water storing halfway into the dry season till midway through the second cropping season. MT-MR for most of the study period had the lowest soil moisture content in the 0-60 cm soil depth at both sites (see Figure 23 and 24).



CT = Conventional Tillage, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation

Figure 25: *Seasonal Soil Moisture content comparison for Treatments in the 0-60cm soil depth of the Component Trial at LRS*



CT = Conventional Tillage, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation

Figure 26: *Seasonal Soil Moisture content comparison for Treatments in the 0-60cm soil depth of the Component Trial at MITC*

4.4.2Soil moisture of the Component Trial in the 0-30 and 0-60 cm soil depth at LRS and MITC over the cropping seasons

There were significant differences with the effect of tillage and CA principles on soil moisture content in the 0-30 cm soil depth of the Component Trial in first season at LRS and in both seasons at MITC (See Figure 27).

Soil moisture content in the 0-30 cm soil depth at LRS ranged from 16.1 mm to 18.8 mm in the first season and 16.6 to 21.6 mm in the second season. At MITC, it ranged from 50.1 mm to 58.9mmand 38.4 to 47.1 mm for the first and second seasons, respectively. At LRS soil moisture content in the 0-30 cm soil depth for most treatments increased from the first season to the second season, except that of MT, and MT-MR. At MITC, the soil moisture content for all treatments decreased from the first season to the second, a response to the decline in the rainfall from 715.2 mm to 530.4mm from the first season to the second (See Figure 27).

In the first season at LRS, MT, MT-M, MT-MR and MT-R in that order had the four highest soil moisture content average results in the 0-30 cm soil depth. MT in the first season had the highest soil moisture reading of 18.8 mm in the 0-30 cm soil depth. In the second season, soil moisture content was insignificantly different from each other (See Figure 27).

In the first season, at MITC, CT-M was found to have the highest soil moisture content in the 0-30 cm soil depth followed by CT (57.7 mm), MT-R (57.6 mm).Like in LRS, CT-R was the least water storing treatment with reading of 50.1 mm. In the second season, MT-M had the highest soil moisture in the 0-30 cm soil depth at 47.1 mm, followed by MT-R (46.1 mm), MT-MR (44.8 mm), CT (44.5 mm).Again CT-R (38.4 mm) was the least water storing (see Figure 27).

Generally, plots in which mulch was incorporated; CT-M, CT-MR, MT-M, MT-MR were among the highest performing plots, having higher soil moisture content than CTa LRS. At MITC only MT-M and MT-MR generally had higher soil moisture than CT.

TREATMENT	0-30 cm Soil depth moisture content LRS		MITC	
	2016/17	**2017/18**	**2016/17**	**2017/18**
CT	16.9 CD	17.6	57.7 AB	44.5 BC
CT-M	17.3 BC	21.6	58.9 A	43.3 CD
CT-R	16.1 D	17.3	50.1 E	38.4 E
CT-MR	17.6 BC	17.9	51.2 DE	42.0 D
MT	18.8 A	18.1	52.7 CDE	43.7 CD
MT-M	18.3 AB	18.3	55.9 ABC	47.1 A
MT-R	17.7 AB	17.9	57.6 AB	46.1 AB
MT-MR	18.2 AB	16.6	54.6 BCD	44.8 BC
P	0.0011	0.624	0.0008	0.0000

CT = Conventional Tillage, CT-M = Conventional Tillage-Mulch, CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. There are groups (A, B, etc.) in which the means are not significantly different from one another and are not comparable across sites and depths

Figure 27: *Soil moisture of the Component Trial in the 0-30 cm soil depth at LRS and MITC*

There were significant differences between the effects of tillage and CA principles on soil moisture content in the 0-60 cm soil depth of the Component Trial in both cropping seasons at both sites ($p<0.05$) (see Figure 28).

Soil moisture content in the 0-60 cm soil depth at LRS ranged from 41.4 mm to 47.2 mm in the first season and 40.5 to 46.6 mm in the second. At MITC, it ranged from 129.2 mm to 153.3 mm and 109.8 to 135.6 mm for the first and second seasons, respectively. At LRS, soil moisture content in the 0-30 cm soil depth for some treatments; namely, CT-M, CT-R, and MT-R increased from the first season to the second, while for CT, CT-MR, MT, MT-M and MT-MR it decreased. Soil moisture content in the 0-60 cm soil depth for all treatments at MITC decreased from the first season to the second, a response to the decline in the rainfall from 715.2 mm to 530.4mm from the first season to the second (See Figure 28).

At both sites, highest soil moisture content was recorded for the MT-Min the 0-60 cm soil depth during both cropping seasons. At LRS, MT-M plots had a mean soil moisture reading of47.2 mm and 46.6 mm in the first and second seasons, respectively. At MITC, the readings were 53.3 mm and 135.6 mm in the first and second seasons. CT, CT-M and CT-R were in that order the least water storing in the 0-60 cm soil depth in the first season. In the second season, CT and CT-R were again among the three least water storing treatments.

In the first season, LRS, MT, MT-R and CT-MR in that order followed MT-M in second, third and fourth, respectively. In the second season, CT-M (45.3 mm)was the second most water storing treatment, followed by MT-R (44.5 mm) (see Figure 28).

In the first season, at MITC,CT (144.1 mm) stored soil moisture second to MT-M and was insignificantly different from MT (143.6 mm) and MT-R (142.3 mm) which ranked third and fourth places, respectively. CA treatments were constantly among the four most water storing treatments in the 0-60 cm soil depth at MITC in the second season.

Generally, CA plots in which mulch was incorporated; namely, MT-M, MT-MR were among the highest performing plots in water retention, particularly, MT-M at both sites. MT-MR was the third highest soil moisture storing treatment in the 0-60 cm soil depth at MITC (See Figure 28).

TREATMENT	0-60cm Soil moisture Content LRS		MITC	
	2016/17	**2017/18**	**2016/17**	**2017/18**
CT	43.3 CDE	42.9 DE	144.1 B	119.2 CD
CT-M	43.8 CD	45.3 B	133.8 CD	112.3 E
CT-R	41.4 E	42.7 E	129.2 D	109.8 E
CT-MR	44.6 BC	43.2 DE	131.5 D	117.1 D
MT	46.0 AB	44.0 CD	143.6 B	123.3 BC
MT-M	47.2 A	46.6 A	153.3 A	135.6 A
MT-R	44.4 BC	44.5 BC	142.3 B	124.8 B
MT-MR	42.4 DE	40.5 F	139.6 BC	121.9 BC
P	0.0001	0.0000	0.0000	0.0000

CT = Conventional Tillage, CT-M = Conventional Tillage-Mulch, CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. There are groups (A, B, etc.) in which the means are not significantly different from one another. And are not comparable sites and depths

Figure 28: *Soil moisture of the Component Trial in the 0-60 cm soil depth at LRS and MITC*

4.5Grain yield of the Systems Trial

4.5.1 Maize grain yield of the Systems Trial

There were no significant differences observed with regards to influence of tillage systems on maize grain yield (p=0.7895) in the first season (see Figure 29).

Similar to season one, there were no statistically significant differences observed with regards to influence of tillage systems on maize gain yield (p=0.2750) in the second season (See Figure 29).

TREATMENT	**Maize Grain Yield (kg/ha)**	
	2016/17	**2017/18**
CTa	1214.5	2915.7
RIBT-C	1301.5	3156.2
RIBT-L	1414.8	3768.7
RIBT	953.8	2762.7
SSM	1210.8	2127.2
DS-M	1080.8	2314.4
BA-M	1346.3	3110.2
MDS-D	1093.8	3007.7
P	0.7895	0.275

CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick. There are 2 groups (A and B) in which the means are not significantly different from one another at $\alpha = 0.05$and are not comparable across seasons

Figure 29: *Maize grain yield of the Systems Trial at LRS*

4.5.2 Cowpea grain yield of the Systems Trial

There were no significant differences observed with regards to the effect of tillage systems on cowpea grain yield in the first season (see Figure 30).

Significant differences were observed on the effect of tillage systems on cowpea grain yield in the second season (p= 0.0026) (see Figure 30). In the second season, SSM and MDS-M plots produced higher cowpea grain yields than CT. SSM plots had the highest cowpea grain yield of 575.0 kg ha^{-1}, followed by MDS-D plots (489.25 kg ha^{-1}) and lastly CTa plots (260.25 kg ha^{-1}) as the least productive of the three treatments (see Figure 30).

TREATMENT	**Cowpea Grain Yield (kg/ha)**	
	2016/17	**2017/18**
CTa	1032.5	260.25 ^{D}
RIBT-C	893.0	361.50 ^{CD}
RIBT-L	985.5	316.75 ^{CD}
RIBT	897.0	499.25 ^{BC}
SSM	988.0	575.00 ^{AB}
DS-M	773.8	608.25 ^{AB}
BA-M	841.0	712.00 ^{A}
MDS-D	951.5	489.25 ^{BC}
P	0.9294	0.0026

CTa = Conventional ploughing (mouldboard, animal traction), RIBT-C = Ripping with a Baufi animal traction ripper – Cowpea intercrop, RIBT-L = Ripping with a Baufi animal traction ripper – Lablab intercrop, RIBT = Ripping with a Baufi animal traction ripper, SSM = Sub-soiling with a Magoye ripper, DS-M = Direct seeding with an animal traction direct seeder, BA-M = Basin Planting, MDS-D = Manual direct seeding with a Dibble stick. Different letters indicate significant differences between means at α = 0.05and are not comparable across seasons

Figure 30: *Cowpea Grain of the Systems Trial at LRS*

4.6 Crop grain yields in the Component Trial

4.6.1 Maize grain yield of the Component Trial

Maize grain yield of the Component Trial at LRS for the first season was not significantly affected by tillage systems and CA principles.

However, during the second season maize grain yield of the Component Trial was significantly affected by tillage systems and CA principles ($p=0.0206$) (see Figure 31). In the second season, CT-MR plots produced the highest maize grain yield of 3852.3 kg ha^{-1}, followed by MT-MR (3550.8 kg ha^{-1}) and CT-M (3371.8 kg ha^{-1}). Minimum tillage with selective incorporation of CA principles yielded increased maize grain yields [MT-M (2920.0 kg ha^{-1}), MT-R (3225.0 kg ha^{-1}) and MT-MR with 3550.8 kg ha^{-1}].MT produced the lowest maize grain yield of 2524.0kg ha^{-1}, and was found to be higher than all the treatments in the first season (see Figure 31).

TREATMENT	Maize Grain Yield (kg/ha)		Yield Improvement (kg/ha)
	2016/17	2017/18	
CT	2023.5	2899.5^{BC}	876
CT-M	2160.3	3371.8^{AB}	1211.5
CT-R	1570.0	2948.3^{BC}	1378.3
CT-MR	1846.5	3852.3^{A}	2005.8
MT	1937.3	2524.0^{C}	586.7
MT-M	1206.8	2920.0^{BC}	1713.2
MT-R	1404.0	3225.0^{ABC}	1812
MT-MR	1142.3	3550.8^{AB}	2407.7
P	0.0884	0.0206	

CT = Conventional Tillage, CT-M = Conventional Tillage-Mulch, CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. Different letters indicate significant differences between least square means at α = 0.05and are not comparable across seasons

Figure 31: *Maize grain yield for the Component Trial at LRS*

4.6.2 Pearl millet grain yield of the Component Trial

Pearl millet grain yield in the Component Trial at MITC was significantly affected by the various treatments in the first cropping season (p =0.0496) and not significantly affected in the second season (see Figure 32).

In the first season, CT produced the highest average pearl millet grain yield of 1783.0 kg ha^{-1}, followed by MT-M and MT which produced pearl millet grain yield of 1562.0 kg ha^{-1} and 1520.8 kg ha^{-1}, respectively. Minimum tillage treatments produced varied average pearl millet grain yields [MT-M produced 1562 kg ha^{-1}, MT-MR produced1439.8 kg ha^{-1} and MT-R plots had the least pearl millet grain yield of all treatments with 1044.8 kg ha^{-1}].

TREATMENT	Pearl millet Grain Yield (kg/ha)	
	2016/17	**2017/18**
CT	1783.0 ^{A}	980.7
CT-M	1369.5 ^{BC}	1051.0
CT-R	1247.0 ^{BC}	935.0
CT-MR	1371.3 ^{ABC}	1137.5
MT	1520.8 ^{AB}	854.9
MT-M	1562.0 ^{AB}	1009.4
MT-R	1044.8 ^{C}	889.0
MT-MR	1439.8 ^{ABC}	1071.8
P	0.0496	0.0752

CT = Conventional Tillage, CT-M = Conventional Tillage-Mulch, CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT = Minimum Tillage, MT-M = Minimum Tillage-Mulch, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. Different letters indicate significant differences between least square means at $\alpha = 0.05$and are not comparable across seasons

Figure 32: *Pearl millet grain yield of the Component Trial at MITC*

4.6.3 Cowpea grain yield of the Component Trial

Cowpea grain yield of the Component Trial for both seasons at LRS was not significantly affected by tillage systems and CA principles (p>0.05) (see Table 14). At MITC, cowpea grain yield of the Component Trial was significantly affected by tillage systems and CA principles during the second season (p=0.037) (see Figure 33).

TREATMENT	**LRS Cowpea Grain Yield (kg/ha)**		**MITC Cowpea Grain Yield (kg/ha)**	
	2016/17	**2017/18**	**2016/17**	**2017/18**
CT-R	827.0	85.5	1398.5	446.25 ^{A}
CT-MR	1233.7	176.0	1105.0	361.50 ^{B}
MT-R	1135.3	153.5	923.0	458.25 ^{A}
MT-MR	1403.8	204.25	901.2	432.00 ^{A}
P	0.3923	0.1442	0.0677	0.037

CT-R = Conventional Tillage-Rotation, CT-MR = Conventional Tillage-Mulch & Rotation, MT-R = Minimum Tillage-Rotation, MT-MR = Minimum Tillage-Mulch & Rotation. Different letters indicate significant differences between least square means at α = 0.05 and are not comparable across seasons and sites

***Figure 33**: Cowpea grain yield of the Component Trial at LRS and MITC*

At MITC, MT-R had the highest cowpea grain yield of 458.25 kg ha^{-1}in second season, an improvement from third place in the first season. MT-MR was the least productive in the first season and improved to third place in the second season (423 kg ha^{-1}) (see Table 14).CT-R was most productive in first season and dropped to second place in the second season with cowpea grain yield of 446.3kg ha^{-1}. CT-MR in second season had an average cowpea grain yield of 361.5kg ha^{-1}, lowest cowpea yield in the season.

5 Discussion

The present study is aimed at determining the effects of Conventional and Conservation Agriculture on soil moisture content, infiltration and crop grain yield at LRS and MITC. The study assessed effects of tillage systems and practices, ground cover, and mulch retention, rotation on crop grain yield, infiltration and soil moisture. This section seeks to discuss these results and answer the research questions and addresses the research objectives based on findings from the study and conclude with a discussion of limitations to the study.

5.1 Infiltration and run-off in the Systems Trial

Infiltration (%) was very high at LRS, >91%in the first season and >94% in the second season. Very high infiltration (%) was a direct influence of the light textured sandy soils which may have contributed to higher percolation. Results coincide with those from neighbouring Zimbabwe, Zambia (Thierfelder & Wall, 2009), in a study in which they found high infiltration was associated to light textured sandy soil. Results also coincide with those from elsewhere showing that higher infiltration and infiltration rates resulting from the absence of tillage (Derpsch et al., 1986), with surface mulch (Roth, 1992).Tisdall & Adem (1986), stated that soil infiltration which influences available soil water and loss is directly proportional to the stability of soil structure. This parameter though was not one of the parameters explored by the study and from an agricultural point of view, is one of the most important aspects and the alteration of this property mainly occurs through human intervention, which results in physical degradation of soil (Badalíkova, 2010), negatively affecting water infiltration and leading to erosion.

5.1 Soil moisture in the Systems Trial

Tillage methods and mulch/residue management did appear to have impacted soil moisture in the 0-30cm and 0-60cm soil depths, similar to findings by Gicheru et al. in 2004 and Fuentes et al. in 2003. Higher soil moisture content on the CA treatment

SSM in both the 0-30 and 0-60 cm soil depth may have been a result of the ridges and furrows harvesting rain water coupled with Mulch that protected and covered the soil reducing the amount of moisture lost to evaporation. According to Mutema et al. (2013) mulch improves air circulation, develops root zone and improves water infiltration and appears to have positively influenced soil moisture content on plots ripped with a Magoye Ripper(SSM) and not plots in which planting stations were prepared with a dibble stick (MDS-M) though it was the least soil disturbed. Conventional tillage treatment CTa had the least soil moisture content in both the 0-30 and 0-60 cm soil depths in the second season, highlighting CTa's poor soil water retention as discovered and described by Fernández et al. in 2009

Throughout the study period, soil moisture content was observed to be fairly similar between all three treatments. Dry spells during the rainy seasons and the dry season between the months May to November were the key periods during which differences in soil moisture between treatments was better observed. The site is predominately sandy, low in organic Carbon and this could have been a big influencing factor for the resultant similar average soil moisture content of the treatments during the rainy seasons. Clearer differences were observed in the dry season, months during which there was no precipitation and humidity was low. Low humidity is known to increase rate of evaporation especially on uncovered soil, in this case the CTa plots as compared to mulched plot SSM and not so much MDS-M.

MDS-M and CTa treatments for most part of the study was having similar soil moisture content and on some occasions had almost the same soil moisture content in both soil depths. In the end, similarities throughout the study eventually contributed to the two treatments to have the same average soil moisture content for the 0-60cm soil depth and insignificantly different average soil moisture content for the 0-30cm soil depth. A study between the years 2005 to 2007 in neighbouring Zimbabwe and Zambia discovered that on average, soil moisture was higher throughout the season in most CA treatments than in the conventionally tilled plots (Thierfelder and Wall, 2009).All treatments recorded their respectively highest reading on different dates in the 0-60cm soil depth and peaked on the same day in the 0-30cm soil depth. In the soil moisture analysis for the 0-60cm soil depth, the CTa treatment peaked in the first season, while, the two CA treatments SSM and MDS-M both peaked in the second season, a possible treatment response to duration of implementation. While in the soil moisture analysis for the 0-30cm soil depth, all three treatments of interest CTa, SSM and MDS-M peaked in the second season. CA treatments SSM and MDS-M appeared to take longer than the conventionally tilled plots to reach its full potential.

5.2 Grain yield of the System Trial

Maize grain yield in the first season was about half that of the second season, while cowpea grain yield was just the opposite. The first season's rainfall pattern was erratic with dry spells experienced in during the progression of the season. The second seasons' rainfall was not as erratic as that of the first season, dry spells too did not frequently occur. This rainfall pattern appears to have positively affected maize grain yield of the second season and hampered that of cowpea for the second season, as it appears cowpeas does not like too much moisture.

The first site LRS was cleared just months before experiments were established and this somewhat virgin land had a number of weeds and broadleaved shrubs that were competing with the crops for water and nutrients. The seed germination in the first season was lower than expected, as the rats ate seeds from within the plots, playing a significant role in reducing the seed germination. The second season was not so heavily impacted by weeds and rats, as the plots were kept clean throughout the dry season prior to seeding. Fewer weeds and lesser broadleaf shrubs for rats to hide under coupled with good rains and good timing of operations appear to have contributed to greater crop grain yield in the second season.

The conventional tillage treatment CTa, which was not mulched and most soil disturbed, appeared to have the highest soil moisture content in the first season. As a result, CTa produced the highest maize grain yield in the first season. An outcome which was somewhat to be expected in the first season as it has been discovered that a majority of the benefits of CA are enjoyed in the long term assoil fertility improves and not immediate, in line with finding by Cannel & Hawes, (1994).In the subsequent season, CTa dropped to second most productive.

CA treatments SSM and MDS-M which had lower soil moisture content than conventional tillage treatment CTa in the first season similarly produced the second highest and least maize grain yield respectively in the first season. In the second season, the SSM treatment which had the highest soil moisture content in the second season and the highest overall average soil moisture content produced the least maize grain yield while MDS-M treatment improved to the most productive of the three tillage systems. Higher overall average soil moisture did not appear to positively influence maize grain yield, as SSM showed an improvement from the first season to the second season. Treatment MDS which had the least average soil moisture content produced the highest maize grain yield in the second season.

Similarly, conventional tillage treatment CTa produced the highest cowpea grain yield in the first season, with CA treatments SSM in second and MDS-D found to have produced the least cowpea grain yield. However, in the subsequent season CA treatment SSM that had the highest soil moisture content in the second season and highest overall average soil moisture content produced the highest cowpea grain yield. Conservation agriculture Treatment MDS-D improved to second and conventional tillage treatment CTa had produced the least cowpea grain yield of the three principal treatments, a complete turnaround to the results of the first season.

Generally, cowpea biomass for the second season was observed to be very high, especially on the CA treatment plots. CA treatments soil moisture retention ability appears to be evident as it encouraged biomass production, but negatively influencing cowpea grain production. Sufficient and well spread rainfall events in second season also appears to have negatively affected cowpea grain yield as it encouraged continued vegetative growth and causing cowpea to have a lot of biomass and lower grain yield.

5.3 Soil moisture in the Component Trial

Soil moisture content in the soil depths 0-30cm and 0-60cm was found to be significantly affected by tillage methods and mulch/residue management at both sites, coinciding with findings by Fuentes et al. in 2003and Gicheru et al. in 2004 that a difference in the water storing capacity of tillage methods. Soil moisture content at LRS where the soil was predominantly sandy ranged from 13.1mm to 14.5mm in the 0-30cm soil depth and ranged from 34.1 to 39.9mm in the 0-60cm soil depth. While at MITC where the soil is sandy loam to loamy, it had average soil moisture content that ranged from 35.1mm to 44mm in the 0-30cm soil depth and ranged from 106.8 to 134.5mm in the 0-60cm soil depth. In the first and second seasons the soil moisture content in the 0-30 cm deep soil depth ranged from 16.1 mm to 18.8 mm and ranged from 16.6 to 21.6 mm at LRS. While, at MITC it ranged from 50.1 mm to 58.9 mm and 38.4 to 47.1 mm for the first and second seasons, respectively. Soil moisture content of both depths at MITC were at least 3-4 times that of LRS, a result dependent mainly by different local environmental factors of each site as compared to the other. MITC is located a few hundred meters from the Kavango River that borders Namibia to Angola in the North. The site is also one of the sites where pearl millet and other crops are irrigated. The soil at MITC is richer in clay and has a greater water holding capacity, explaining why the site has higher soil moisture content than LRS.

Generally, CA (Minimum tillage) treatments had higher average soil moisture as compared to Conventional tillage treatments throughout the study period and during both cropping seasons at both sites in both soil depths, particularly CA treatments MT-M and MT.

CA treatment MT-M in both localities had the highest average soil moisture content followed by another CA treatment, MT in both the 0-30cm and 0-60cm soil depths. Conventional tillage treatment CT in LRS was the second least water storing treatment while at MITC it was mid ranked at fourth, insignificantly different from MT-MR in soil depths 0-60cm.

MT-M and MT in that order had higher soil moisture content than CT treatments throughout the study period at both sites in the 0-60cm soil depths. While in the 0-30cm soil depth, three Minimum tillage treatments; MT-M, MT and MT-R were found to have higher soil moisture content than CT at LRS and only MT-M and MTR had higher soil moisture content in the top 30cm deep soil at MITC. The dry season was the period during which differences in soil moisture content was best observed. MT-MR that included a maize-cowpea and pearl millet-cowpea rotation was among the lowest average soil moisture content in both 0-30cm and 0-60cm soil depths at both sites, an observation that was puzzling as it was mulched and had a rotational crop cowpea that had a lot of biomass and served as a living blanket. These results generally portrayed that minimum tillage systems conserve more soil moisture in the depth than traditional tillage. Generally, plots in which mulch was incorporated; CT-M, CT-MR, MT-M , MT-MR were among the high performing plots, found to have higher soil moisture content than CT only at LRS, whilst at MITC, only MT-M and MT-MR generally had higher soil moisture than the treatment: CT only. Similar findings are reported by McHugh, Steenhuis, Abebe, & Fernández. (2007), Pansak, Hilger, Dercon, Kongkaew, & Cadisch. (2008) and Govaerts, Sayre, Goudeseune, De Corte, Lichter, Dendooven, & Deckers, (2009), who further explained that in part the crop residues maintained on the surface in these system, produced less evaporation, greater infiltration and increased soil moisture.

5.4 Grain yield of the Component Trial

Generally, in the first season (2016/17) conventional tillage treatments were found to have higher maize and pearl millet grain yield than CA (Minimum tillage) treatments. Maize grain yield followed the order CT-M >CT> MT >CT-MR >CT-R > MT-R > MT-M > MT-MR, highlighting Conventional tillage's reign in the first season. MT-MR was found to have the least maize yield in the first season, a reflection of MT-MR's inability to conserve soil moisture as highlighted in the soil moisture results. While at MITC, pearl millet grain yield for the first season followed the order CT> MT-M > MT > MT-MR >CT-MR >CT-M >CT-R > MT-R.

In the second season 2017/18, maize grain yields followed the order CT-MR > MT-MR >CT-M > MT-R >CT-R > MT-M >CT>MT after a wet season during which soil moisture was very similar at LRS. On the other hand, pearl millet grain yields followed the order CT-MR > MT-MR >CT-M > MT-M >CT>CT-R >MT-R >MT with a CT-MR highest and MT least productive in both sites. Mulch coupled with crop rotation appears to have positively affected maize as mulch resulted in increased soil moisture and crop rotation improving soil fertility, improving maize grain. From the soil moisture findings reported by McHugh et al., (2007), Pansak, (2008) and Govaerts et al., (2009), higher soil moisture due to mulch appears to have positively influenced maize and pearl millet grain yields in the second season. In the second season at LRS, MT-MR had the highest maize grain yield of all the CA treatments and second highest overall, complete opposite to the first season. MT-M and MT in that order had higher soil moisture content than conventional tillage treatments, but their maize and pearl millet grain yields were generally lower than that of CT at both sites

In both cropping seasons at LRS, cowpea grain yield production following the order MT-MR >CT-MR > MT-R >CT-R with plot having mulch coupled with rotation the best producers. However, at MITC, cowpea grain yields followed the order CT-R >CT-MR > MT-R > MT-MR in first season but in the second season the order changed to CT-R > MT-R > MT-MR >CT-MR. MITC soil is richer in clay and has a greater water holding capacity resulting in higher observed soil moisture that encouraged continued vegetative growth and lower grain production. MT-MR had the highest cowpea grain yield in both cropping seasons at LRS were the soil is predominantly sandy while at MITC MT-MR fell within the bottom half producing the least cowpea grain yield in the first season and second least productive in the second season. Sufficient and well spread rainfall events in second season appears to have negatively affected cowpea grain yield as it encouraged continued vegetative growth and causing cowpea to have a lot of biomass and lower grain yield.

Mulched plots, CT-MR, MT-MR, CT-M and MT-M generally had higher maize and pearl millet grain yields than plots not mulched. While cowpea was lower on those same plots at MITC.

6 Conclusion

Crop production forms an integral part of the livelihood of a large portion of the Namibian population. Several tillage systems and practices are known to be implemented by farmers, some of which may improve crop yield, water infiltration and water storage. The present study aimed to determine the effects of Conventional and Conservation Agriculture on soil moisture content, infiltration and crop grain yield in Liselo Research Station (LRS) and Mashare Irrigation Training Center (MITC). The study assessed effects of tillage systems and practices, ground cover, and mulch retention, rotation on crop grain yield, infiltration and soil moisture. This section highlights the overall findings from the study, provides recommendations for smallholder farmers practicing these tillage methods in northern Namibia, and winds up with suggestions for future research.

6.1 General findings

Effect of tillage systems of the Systems Trial on infiltration, run-off, soil moisture and crop grain yield

A. Tillage methods did not appear to significantly influence total infiltration (%), though marginally greater on CA plots; SSM and MDS-M. High infiltration and resulting low run-off could be more a result of the light textured sandy soils and tillage system which contributed to observed results.

B. Tillage methods did appear to significantly influence soil moisture in the 0-30 cm and 0-60cm soil depth. Generally, SSM plots were for most part of the study period the tillage method of choice, having higher soil moisture content in the entire 0-30cm and 0-60cm column, and being significantly different from the other treatments. Initially, the CTa treatment appeared to have higher soil moisture in both soil depths until the dry season when the CA treatment SSM had higher soil moisture. Mulch and furrows prepared with the magoye ripper did appear to positively influence soil moisture content sufficiently in the SSM plots.

C. Tillage systems were only found to have significantly affected cowpea grain yield in the second cropping season, while maize grain yield did not appear significantly affected by tillage systems. Maize grain yield of the first season was less than half that of the subsequent season 2017/18, while cowpea grain yield of the first season was much higher than that of the second season. CTa outperformed the other treatments with regards to both maize and cowpea grain yields in the first season and dropped to second most productive and least productive in the subsequent season for maize and cowpea respectively. MDS-D plots produce the least maize grain and cowpea grain yields in the first cropping season and improved to highest (maize) and second highest (cowpea) yields in the second season. SSM plots which had the highest average soil moisture content produced the second highest maize grain and cowpea grain yields in the first season and dropped to least productive (maize) and most productive (cowpea) of the three tillage systems in the second season.

D. Sufficient and well spread rainfall events in second season appears to have negatively affected cowpea grain yield as it encouraged continued vegetative growth and causing cowpea to have a lot of biomass and lower grain yield.

Effects of tillage systems and principle of the Component Trial on soil moisture and crop grain yield

E. Tillage systems and CA Principle (Minimum soil disturbance, permanent soil cover and Crop rotation) did significantly influence soil moisture and grain yield in both localities. Generally, CA (Minimum tillage) treatments had higher average soil moisture as compared to Conventional tillage treatments throughout the study period at both sites, particularly MT-M and MT. Of all treatments MT-

MR that included a maize-cowpea and pearl millet-cowpea rotation had the lowest soil moisture content at both sites.

F. Tillage systems and components significantly affected maize grain yield at LRS in the second season, Pearl Millet grain yield at MITC in the first season and cowpea grain yield at MITC in the second season. Mulched plots with maize-cowpea and pearl millet-cowpea rotation (CT-MR and MT-MR) and mulched only plots (CT-M and MT-M) generally had higher crop grain yield than plots not mulched or rotated only. Maize grain yields were found to follow no particular fixed order but rather had changing orders over the two seasons.

G. Generally, CT plots during the first season had higher maize and pearl millet grain yields than CA (Minimum tillage) treatments at LRS and MITC, respectively. Minimum tillage treatments in general produced less than 1500 kg ha^{-1} maize grain yield in the first season and more than 2500 kg ha^{-1} in the second season. MT-R had the least pearl millet grain yield of all treatments in the first season while, in the second season MT was the least productive. In the second season 2017/18, pearl millet grain yields followed the order CT-MR > MT-MR >CT-M > MT-M >CT>CT-R >MT-R >MT clearly showing mulch's influence on crop yield. In contrast to maize and pearl millet, cowpea grain yields at LRS were higher on plots with rotation only for both tillage systems. However, at MITC, cowpea grain yields showed mixed results with one constant: CT-R had the highest cowpea grain yields in both seasons. Sufficient and well spread rainfall events may appear to have negatively affected cowpea grain yield as it encouraged continued vegetative growth and caused lower grain yield and grain loss, as some got spoiled. This may explain the huge differences in cowpea grain yield over the two seasons.

6.2 Conclusion of the thesis

Upon the completion of data analysis and discussion, both hypotheses were rejected. Results of data analysis highlighted that most of the results were statistically significant while a few were not. Hypothesis one was rejected on the basis that tillage methods did have an impact on the amount of moisture available in the soil between season and throughout the study period. Infiltration, which was also a part of the first objective was insignificantly affected by tillage treatments, proving the hypothesis right. The second hypothesis was rejected because tillage methods, individual CA principles and a combination of them were found to have affected soil moisture during the cropping seasons and throughout the study period.

This study has in part proven that reduced soil disturbance and residue mulch application could improve conservation of soil moisture, enhance better crop performance and improve crop biomass and grain yield production. It can also be concluded that maize, cowpea and pearl millet can be grown successfully under residue/mulch in Namibia's harsh climatic conditions. It appears that Conservation Agriculture practices are beneficial in sandy and sandy loamy soils of northern Namibia. Large amounts of biomass produced by the cereal crops due to increased soil moisture when left as mulch can be a rich source of organic matter. They can also be used to protect the soil from erosion during the winter months, diminish weed growth and improve water infiltration into the soil during the summer cropping season. Conservation agriculture practices have great potential to benefit maize, cowpea and pearl millet production in the Northern regions of Namibia. For this reason, adequate management practices must continue to be developed.

6.3 Recommendations and future research

Permanent soil cover through mulching are recommended despite the problems associated with the materials used and their availability. Other factors which may restrict use of cover crops are, smaller land holdings, increased human population and more livestock which may feed on the material. In the absence of crop residue mulch, sub-soiling with magoye ripper is recommended to increase soil moisture. This tillage practice could encourage infiltration by opening up furrows in which water is channeled, facilitating water harvesting. Results presented in this thesis highlight findings from two seasons. Further research work is recommended by monitoring the long-term effects of tillage practices on infiltration, run-off, soil moisture content, crop performance and crop grain yield.

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8 Appendices

CENTRE FOR POSTGRADUATE STUDIES

University of Namibia, Private Bag 13301, Windhoek, Namibia
340 Mandume Ndemufayo Avenue, Pioneers Park
☎ +264 61 206 3275/4662; Fax +264 61 206 3290; URL: http://www.unam.edu.na

UNAM
UNIVERSITY OF NAMIBIA

RESEARCH PERMISSION LETTER

25 October 2017

Student Name: Mr Kudumo P. Ladislcus

Student number: 201117479

Programme: ***MSc (Crop Science)***

Approved research title: Effects of conventional agriculture and conservation agriculture on soil water moisture content, infiltration and crop yield at Liselo and Mashare, Namibia

TO WHOM IT MAY CONCERN

I hereby confirm that the above mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

Dr M Hedimbi
Director: Centre for Postgraduate Studies
Tel: +264 61 2063275
E-mail: directorpgs@unam.na

25 Oct 17
Date

Figure 34: Research permission letter

Table 1: *Soil Moisture Content Results for entire study period in the 0-30 cm Soil Depth in the Systems Trial at LRS (Statistix 9 Analysis Output)*

```
Statistix 9.0                                                  11/4/2018, 10:11:32
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Replicate    15   3783.17   252.212
Treatment     7     82.51    11.787     7.63   0.0000
Error       105    162.24     1.545
Total       127

Note: SS are marginal (type III) sums of squares

Grand Mean 13.651    CV 9.11

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1     2.520   2.52033    1.64   0.2030
Remainder      104   159.721   1.53578

Relative Efficiency, RCB 20.16

Means of Soil for Treatment

Treatment    Mean
BA-M       13.546
CTa        14.374
DS-M       13.552
MDS-D      14.113
RIBT       12.864
RIBT-C     12.131
RIBT-L     13.766
SSM        14.858
Observations per Mean           16
Standard Error of a Mean    0.3108
Std Error (Diff of 2 Means) 0.4395


Statistix 9.0                                                  11/4/2018, 10:12:43
AM

LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
SSM        14.858  A
CTa        14.374  AB
MDS-D      14.113  AB
RIBT-L     13.766   B
DS-M       13.552   BC
BA-M       13.546   BC
RIBT       12.864    CD
RIBT-C     12.131     D

Alpha              0.05     Standard Error for Comparison  0.4395
Critical T Value  1.983     Critical Value for Comparison  0.8714
Error term used: Replicate*Treatment, 105 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 2: *Soil Moisture Content Results for first season (2016/17) in the 0-30 cm Soil Depth in the Systems Trial at LRS (Statistix 9 Analysis Output)*

```
Statistix 9.0                                                11/13/2018, 10:33:18
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS       F        P
Month         3   253.730   84.5766
Treatment     7    48.500    6.9285    1.59   0.1930
Error        21    91.501    4.3572
Total        31

Note: SS are marginal (type III) sums of squares

Grand Mean 15.850    CV 13.17

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source           DF        SS        MS       F        P
Nonadditivity     1   29.1711   29.1711    9.36   0.0062
Remainder        20   62.3294    3.1165

Relative Efficiency, RCB 2.78

Means of Soil for Treatment

Treatment    Mean
BA-M       14.605
CTa        17.830
DS-M       15.041
MDS-D      16.868
RIBT       14.052
RIBT-C     15.146
RIBT-L     16.509
SSM        16.746
Observations per Mean            4
Standard Error of a Mean    1.0437
Std Error (Diff of 2 Means) 1.4760


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
CTa        17.830  A
MDS-D      16.868  AB
SSM        16.746  AB
RIBT-L     16.509  AB
RIBT-C     15.146  AB
DS-M       15.041  AB
BA-M       14.605   B
RIBT       14.052   B


Alpha              0.05     Standard Error for Comparison  1.4760
Critical T Value  2.080     Critical Value for Comparison  3.0695
Error term used: Month*Treatment, 21 DF
There are 2 groups (A and B) in which the means are not significantly
different from one another.
```

Table 3: *Soil Moisture Content Results for second season (2017/18) in the 0-30 cm Soil Depth in the Systems Trial at LRS (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/13/2018, 10:39:32
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Month         5   686.469   137.294
Treatment     7    57.664     8.238    11.08   0.0000
Error        35    26.031     0.744
Total        47

Note: SS are marginal (type III) sums of squares

Grand Mean 18.036    CV 4.78

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source           DF        SS        MS       F        P
Nonadditivity     1    0.4899   0.48994    0.65   0.4249
Remainder        34   25.5414   0.75122

Relative Efficiency, RCB 20.53

Means of Soil for Treatment

Treatment    Mean
BA-M       18.662
CTa        18.176
DS-M       18.308
MDS-D      18.137
RIBT       17.776
RIBT-C     15.599
RIBT-L     17.843
SSM        19.788
Observations per Mean            6
Standard Error of a Mean    0.3521
Std Error (Diff of 2 Means) 0.4979


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
SSM        19.788  A
BA-M       18.662   B
DS-M       18.308   B
CTa        18.176   B
MDS-D      18.137   B
RIBT-L     17.843   B
RIBT       17.776   B
RIBT-C     15.599    C

Alpha              0.05     Standard Error for Comparison  0.4979
Critical T Value  2.030     Critical Value for Comparison  1.0108
Error term used: Month*Treatment, 35 DF
There are 3 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 4: *Soil Moisture Content Results for the Systems Trial at LRS in the 0-60 cm Soil Depth over the entire study period (Statistix 9 Analysis Output)*

Statistix 9.0 9/25/2018, 11:58:01 AM

Randomized Complete Block AOV Table for Soil

Source	DF	SS	MS	F	P
Replicate	15	14932.5	995.497		
Treatment	7	308.1	44.011	25.66	0.0000
Error	105	180.1	1.715		
Total	127				

Note: SS are marginal (type III) sums of squares

Grand Mean 38.252 CV 3.42

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	1.332	1.33166	0.77	0.3808
Remainder	104	178.779	1.71903		

Relative Efficiency, RCB 69.43

Means of Soil for treatment

Treatment	Mean
BA-M	38.642
CTa	39.281
DS-M	38.699
MDS-D	39.297
RIBT	36.416
RIBT-C	35.393
RIBT-L	37.800
SSM	40.489

Observations per Mean 16
Standard Error of a Mean 0.3274
Std Error (Diff of 2 Means) 0.4631

Statistix 9.0 9/25/2018, 12:07:59 PM

LSD All-Pair wise Comparisons Test of Soil for treatment

Treatment	Mean	Homogeneous Groups
SSM	40.489	A
MDS-D	39.297	B
CTa	39.281	B
DS-M	38.699	BC
BA-M	38.642	BC
RIBT-L	37.800	C
RIBT	36.416	D
RIBT-C	35.393	E

Alpha 0.05 Standard Error for Comparison 0.4631
Critical T Value 1.983 Critical Value for Comparison 0.9181
Error term used: replicate*treatment, 105 DF
There are 5 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 5: *Soil Moisture Content Results over the first season (2016/17) for the Systems Trial at LRS in the 0-60 cm Soil Depth (Statistix 9 Analysis Output)*

```
Statistix 9.0                                             11/13/2018, 10:37:26
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        3   1455.12   485.040
Treatment    7     49.90     7.129     8.88   0.0000
Error       21     16.86     0.803
Total       31

Note: SS are marginal (type III) sums of squares

Grand Mean 42.449    CV 2.11

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    0.2120   0.21204    0.25   0.6193
Remainder       20   16.6493   0.83247

Relative Efficiency, RCB 59.36

Means of Soil for Treatment

Treatment    Mean
BA-M       42.736
CTa        44.422
DS-M       43.318
MDS-D      43.157
RIBT       40.597
RIBT-C     40.629
RIBT-L     41.875
SSM        42.862
Observations per Mean            4
Standard Error of a Mean    0.4480
Std Error (Diff of 2 Means) 0.6336


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
CTa        44.422  A
DS-M       43.318  AB
MDS-D      43.157  ABC
SSM        42.862   BC
BA-M       42.736   BC
RIBT-L     41.875    CD
RIBT-C     40.629     D
RIBT       40.597     D

Alpha              0.05     Standard Error for Comparison  0.6336
Critical T Value  2.080     Critical Value for Comparison  1.3177
Error term used: Month*Treatment, 21 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 6: *Soil Moisture Content Results for the second season (2017/18) in the 0-60 cm Soil Depth of the Systems Trial at LRS (Statistix 9 Analysis Output)*

```
Statistix 9.0                                          11/13/2018, 10:40:58
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        5   2869.10   573.820
Treatment    7    222.72    31.816    11.93   0.0000
Error       35     93.31     2.666
Total       47

Note: SS are marginal (type III) sums of squares

Grand Mean 46.846    CV 3.49

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    1.0414   1.04139    0.38   0.5397
Remainder       34   92.2645   2.71366

Relative Efficiency, RCB 23.79

Means of Soil for Treatment

Treatment    Mean
BA-M       47.761
CTa        47.222
DS-M       47.542
MDS-D      47.751
RIBT       45.105
RIBT-C     42.629
RIBT-L     46.221
SSM        50.538
Observations per Mean            6
Standard Error of a Mean    0.6666
Std Error (Diff of 2 Means) 0.9427


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
SSM        50.538  A
BA-M       47.761   B
MDS-D      47.751   B
DS-M       47.542   B
CTa        47.222   B
RIBT-L     46.221   BC
RIBT       45.105    C
RIBT-C     42.629     D

Alpha              0.05     Standard Error for Comparison  0.9427
Critical T Value  2.030     Critical Value for Comparison  1.9137
Error term used: Month*Treatment, 35 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 7: *LRS Component Trial Soil Moisture Content Results for the 0-30cm Soil Depth over the entire study period (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/4/2018, 9:24:00
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Replicate    15   4533.52   302.234
Treatment     7     24.84     3.549     8.07   0.0000
Error       105     46.19     0.440
Total       127

Note: SS are marginal (type III) sums of squares

Grand Mean 13.915    CV 4.77

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    0.6881   0.68807    1.57   0.2126
Remainder      104   45.5012   0.43751

Relative Efficiency, RCB 82.03

Means of Soil for Treatment

Treatment    Mean
CT         13.663
CT-M       13.963
CT-MR      14.115
CT-R       13.133
MT         14.432
MT-M       14.547
MT-MR      13.508
MT-R       13.961
Observations per Mean           16
Standard Error of a Mean    0.1658
Std Error (Diff of 2 Means) 0.2345



LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       14.547  A
MT         14.432  A
CT-MR      14.115  AB
CT-M       13.963   BC
MT-R       13.961   BC
CT         13.663   BC
MT-MR      13.508    CD
CT-R       13.133     D

Alpha              0.05     Standard Error for Comparison  0.2345
Critical T Value  1.983     Critical Value for Comparison  0.4650
Error term used: Replicate*Treatment, 105 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 8: *MITC Components Soil Moisture Content Results for the 0-30 cm Soil Depth Average over the entire study period (Statistix 9 Analysis Output)*

```
Statistix 9.0                                               11/4/2018, 8:34:58
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Replicate    14   15734.6   1123.90
Treatment     7     895.1    127.87    35.96   0.0000
Error        98     348.4      3.56
Total       119

Note: SS are marginal (type III) sums of squares

Grand Mean 40.356    CV 4.67

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    17.321   17.3211    5.07   0.0265
Remainder       97   331.116    3.4136

Relative Efficiency, RCB 38.07

Means of Soil for Treatment

Treatment    Mean
CT         41.489
CT-M       41.276
CT-MR      37.265
CT-R       35.063
MT         40.063
MT-M       43.998
MT-MR      40.800
MT-R       42.891
Observations per Mean          15
Standard Error of a Mean    0.4869
Std Error (Diff of 2 Means) 0.6885


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       43.998  A
MT-R       42.891  A
CT         41.489   B
CT-M       41.276   BC
MT-MR      40.800   BC
MT         40.063    C
CT-MR      37.265     D
CT-R       35.063      E

Alpha              0.05     Standard Error for Comparison  0.6885
Critical T Value  1.984     Critical Value for Comparison  1.3664
Error term used: Replicate*Treatment, 98 DF
There are 5 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 9: *Soil Moisture Content Results for the LRS Component Trial in0-30 cm Soil Depth for the first season (2016/17) (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/13/2018, 10:19:48
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        3   668.587   222.862
Treatment    7    20.355     2.908     5.45   0.0011
Error       21    11.213     0.534
Total       31

Note: SS are marginal (type III) sums of squares

Grand Mean 17.605    CV 4.15

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1   2.96838   2.96838    7.20   0.0143
Remainder       20   8.24467   0.41223

Relative Efficiency, RCB 41.29

Means of Soil for Treatment

Treatment    Mean
CT         16.895
CT-M       17.256
CT-MR      17.637
CT-R       16.093
MT         18.752
MT-M       18.283
MT-MR      18.232
MT-R       17.696
Observations per Mean            4
Standard Error of a Mean    0.3654
Std Error (Diff of 2 Means) 0.5167


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT         18.752  A
MT-M       18.283  AB
MT-MR      18.232  AB
MT-R       17.696  ABC
CT-MR      17.637   BC
CT-M       17.256   BC
CT         16.895    CD
CT-R       16.093     D

Alpha              0.05     Standard Error for Comparison  0.5167
Critical T Value  2.080     Critical Value for Comparison  1.0745
Error term used: Month*Treatment, 21 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 10: *Soil Moisture Content Results in0-30 cm Soil Depth for the first season (2016/17) for the MITC Component Trial (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/13/2018, 10:14:14
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        2   1386.93   693.463
Treatment    7    222.31    31.758     7.33   0.0008
Error       14     60.69     4.335
Total       23

Note: SS are marginal (type III) sums of squares

Grand Mean 54.829    CV 3.80

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    5.8947   5.89473    1.40   0.2582
Remainder       13   54.7967   4.21513

Relative Efficiency, RCB 14.62

Means of Soil for Treatment

Treatment    Mean
CT         57.666
CT-M       58.862
CT-MR      51.174
CT-R       50.067
MT         52.700
MT-M       55.911
MT-MR      54.594
MT-R       57.657
Observations per Mean            3
Standard Error of a Mean    1.2021
Std Error (Diff of 2 Means) 1.7000


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
CT-M       58.862  A
CT         57.666  AB
MT-R       57.657  AB
MT-M       55.911  ABC
MT-MR      54.594   BCD
MT         52.700    CDE
CT-MR      51.174     DE
CT-R       50.067      E

Alpha              0.05     Standard Error for Comparison  1.7000
Critical T Value  2.145     Critical Value for Comparison  3.6462
Error term used: Month*Treatment, 14 DF
There are 5 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 11: *Soil Moisture Content Results for the LRS Component Trial in0-30 cm Soil Depth for the second (2017/18) season (Statistix 9 Analysis Output)*

```
Statistix 9.0                                          11/13/2018, 10:22:52
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS      F        P
Month        5   362.004   72.4009
Treatment    7    95.386   13.6266   0.76   0.6240
Error       35   627.500   17.9286
Total       47

Note: SS are marginal (type III) sums of squares

Grand Mean 18.149    CV 23.33

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1   219.088   219.088   18.24   0.0001
Remainder       34   408.413    12.012

Relative Efficiency, RCB 1.32

Means of Soil for Treatment

Treatment    Mean
CT         17.612
CT-M       21.636
CT-MR      17.884
CT-R       17.268
MT         18.054
MT-M       18.255
MT-MR      16.556
MT-R       17.927
Observations per Mean           6
Standard Error of a Mean    1.7286
Std Error (Diff of 2 Means) 2.4446


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
CT-M       21.636  A
MT-M       18.255  AB
MT         18.054  AB
MT-R       17.927  AB
CT-MR      17.884  AB
CT         17.612  AB
CT-R       17.268  AB
MT-MR      16.556   B

Alpha              0.05     Standard Error for Comparison  2.4446
Critical T Value  2.030     Critical Value for Comparison  4.9629
Error term used: Month*Treatment, 35 DF
There are 2 groups (A and B) in which the means are not significantly
different from one another.
```

Table 12: *Soil Moisture Content Results in0-30 cm Soil Depth for the second season (2018/18) for the MITC Component Trial (Statistix 9 Analysis Output)*

```
Statistix 9.0                                         11/13/2018, 10:10:37
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        5   2105.84   421.169
Treatment    7    299.93    42.847    11.82   0.0000
Error       35    126.83     3.624
Total       47

Note: SS are marginal (type III) sums of squares

Grand Mean 43.760    CV 4.35

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1     3.399   3.39942    0.94   0.3400
Remainder       34   123.435   3.63043

Relative Efficiency, RCB 13.26

Means of Soil for Treatment

Treatment    Mean
CT         44.541
CT-M       43.283
CT-MR      42.040
CT-R       38.448
MT         43.694
MT-M       47.119
MT-MR      44.843
MT-R       46.109
Observations per Mean            6
Standard Error of a Mean    0.7772
Std Error (Diff of 2 Means) 1.0991


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       47.119  A
MT-R       46.109  AB
MT-MR      44.843   BC
CT         44.541   BC
MT         43.694    CD
CT-M       43.283    CD
CT-MR      42.040     D
CT-R       38.448      E

Alpha              0.05     Standard Error for Comparison  1.0991
Critical T Value  2.030     Critical Value for Comparison  2.2312
Error term used: Month*Treatment, 35 DF
There are 5 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 13: *LRS Component Trial Soil Moisture Content Results for the 0-60cm Soil Depth over the entire study period (Statistix 9 Analysis Output)*

Statistix 9.0 9/25/2018, 10:47:19 AM

Randomized Complete Block AOV Table for Soil

Source	DF	SS	MS	F	P
Replicate	14	12856.3	918.309		
Treatment	7	308.8	44.113	37.12	0.0000
Error	98	116.4	1.188		
Total	119				

Note: SS are marginal (type III) sums of squares

Grand Mean 36.721 CV 2.97

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	0.079	0.07925	0.07	0.7977
Remainder	97	116.369	1.19968		

Relative Efficiency, RCB 91.80

Means of Soil for treatment

Treatment	Mean
CT	36.144
CT-M	37.163
CT-MR	36.857
CT-R	35.051
MT	37.693
MT-M	39.814
MT-MR	34.133
MT-R	36.911

Observations per Mean 15
Standard Error of a Mean 0.2815
Std Error (Diff of 2 Means) 0.3980

Statistix 9.0 9/25/2018, 10:56:32 AM

LSD All-Pair wise Comparisons Test of Soil for treatment

Treatment	Mean	Homogeneous Groups
MT-M	39.814	A
MT	37.693	B
CT-M	37.163	BC
MT-R	36.911	BCD
CT-MR	36.857	CD
CT	36.144	D
CT-R	35.051	E
MT-MR	34.133	F

Alpha 0.05 Standard Error for Comparison 0.3980
Critical T Value 1.984 Critical Value for Comparison 0.7899
Error term used: replicate*treatment, 98 DF
There are 6 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 14: *LRS Component Trial Soil Moisture Content Results for the 0-60 cm Soil Depth over the first season (2016/17) (Statistix 9 Analysis Output)*

```
Statistix 9.0                                          11/13/2018, 10:21:41
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        3   2187.89   729.296
Treatment    7     96.82    13.831     8.66   0.0001
Error       21     33.55     1.598
Total       31

Note: SS are marginal (type III) sums of squares

Grand Mean 44.152    CV 2.86

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1    3.4105   3.41053    2.26   0.1481
Remainder       20   30.1412   1.50706

Relative Efficiency, RCB 45.08

Means of Soil for Treatment

Treatment    Mean
CT         43.303
CT-M       43.831
CT-MR      44.641
CT-R       41.445
MT         45.966
MT-M       47.206
MT-MR      42.389
MT-R       44.438
Observations per Mean            4
Standard Error of a Mean    0.6320
Std Error (Diff of 2 Means) 0.8938


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       47.206  A
MT         45.966  AB
CT-MR      44.641   BC
MT-R       44.438   BC
CT-M       43.831    CD
CT         43.303    CDE
MT-MR      42.389     DE
CT-R       41.445      E

Alpha              0.05     Standard Error for Comparison  0.8938
Critical T Value  2.080     Critical Value for Comparison  1.8587
Error term used: Month*Treatment, 21 DF
There are 5 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 15: *LRS Component Trial Soil Moisture Content Results for the 0-60 cm Soil Depth over the second season (2017/18) (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/13/2018, 10:24:22
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Month         5   1579.20   315.841
Treatment     7    142.80    20.401    20.09   0.0000
Error        35     35.53     1.015
Total        47

Note: SS are marginal (type III) sums of squares

Grand Mean 43.724    CV 2.30

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source           DF        SS        MS       F        P
Nonadditivity     1    0.1712   0.17121    0.16   0.6875
Remainder        34   35.3611   1.04003

Relative Efficiency, RCB 33.99

Means of Soil for Treatment

Treatment    Mean
CT         42.919
CT-M       45.301
CT-MR      43.206
CT-R       42.748
MT         43.994
MT-M       46.603
MT-MR      40.493
MT-R       44.527
Observations per Mean            6
Standard Error of a Mean    0.4113
Std Error (Diff of 2 Means) 0.5817


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       46.603  A
CT-M       45.301   B
MT-R       44.527   BC
MT         43.994    CD
CT-MR      43.206     DE
CT         42.919     DE
CT-R       42.748      E
MT-MR      40.493       F

Alpha              0.05     Standard Error for Comparison  0.5817
Critical T Value  2.030     Critical Value for Comparison  1.1810
Error term used: Month*Treatment, 35 DF
There are 6 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 16: *Soil Moisture Content Results in the 0-60cm Soil Depth for the MITC Component Trial over the entire study period (Statistix 9 Analysis Output)*

Statistix 9.0 9/25/2018, 9:24:35 AM

Randomized Complete Block AOV Table for soil

Source	DF	SS	MS	F	P
Replicate	14	36167.0	2583.36		
Treatment	7	8131.1	1161.58	88.04	0.0000
Error	98	1293.0	13.19		
Total	119				

Note: SS are marginal (type III) sums of squares

Grand Mean 117.28 CV 3.10

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	281.21	281.208	26.96	0.0000
Remainder	97	1011.76	10.431		

Relative Efficiency, RCB 23.92

Means of soil for treatment

Treatment	Mean
CT	117.57
CT-M	110.04
CT-MR	109.86
CT-R	106.82
MT	121.73
MT-M	134.51
MT-MR	117.56
MT-R	120.18

Observations per Mean 15
Standard Error of a Mean 0.9379
Std Error (Diff of 2 Means) 1.3263

Statistix 9.0 9/25/2018, 9:26:59 AM

LSD All-Pair wise Comparisons Test of soil for treatment

Treatment	Mean	Homogeneous Groups
MT-M	134.51	A
MT	121.73	B
MT-R	120.18	BC
CT	117.57	C
MT-MR	117.56	C
CT-M	110.04	D
CT-MR	109.86	D
CT-R	106.82	E

Alpha 0.05 Standard Error for Comparison 1.3263
Critical T Value 1.984 Critical Value for Comparison 2.6321
Error term used: replicate*treatment, 98 DF
There are 5 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 17: *Soil Moisture Content Results in the 0-60 cm Soil Depth for the MITC Component Trial over the first season (2016/17) (Statistix 9 Analysis Output)*

```
Statistix 9.0                                              11/13/2018, 10:16:39
AM

Randomized Complete Block AOV Table for Soil

Source       DF        SS        MS        F        P
Month         2   3819.26   1909.63
Treatment     7   1322.30    188.90    13.16   0.0000
Error        14    200.98     14.36
Total        23

Note: SS are marginal (type III) sums of squares

Grand Mean 139.65    CV 2.71

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source           DF        SS        MS       F        P
Nonadditivity     1    78.635   78.6355    8.36   0.0126
Remainder        13   122.345    9.4111

Relative Efficiency, RCB 12.31

Means of Soil for Treatment

Treatment    Mean
CT         144.08
CT-M       133.77
CT-MR      131.45
CT-R       129.15
MT         143.60
MT-M       153.31
MT-MR      139.60
MT-R       142.26
Observations per Mean            3
Standard Error of a Mean    2.1875
Std Error (Diff of 2 Means) 3.0936


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       153.31  A
CT         144.08   B
MT         143.60   B
MT-R       142.26   B
MT-MR      139.60   BC
CT-M       133.77    CD
CT-MR      131.45     D
CT-R       129.15     D

Alpha              0.05     Standard Error for Comparison  3.0936
Critical T Value  2.145     Critical Value for Comparison  6.6352
Error term used: Month*Treatment, 14 DF
There are 4 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 18: *Soil Moisture Content Results over the second season (2017/18) in the 0-60 cm Soil Depth for the MITC Component Trial (Statistix 9 Analysis Output)*

```
Statistix 9.0                                          11/13/2018, 10:06:39
AM

Randomized Complete Block AOV Table for Soil

Source      DF        SS        MS        F        P
Month        5   7962.94   1592.59
Treatment    7   2701.94    385.99    30.71   0.0000
Error       35    439.88     12.57
Total       47

Note: SS are marginal (type III) sums of squares

Grand Mean 120.50    CV 2.94

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source          DF        SS        MS       F        P
Nonadditivity    1   130.371   130.371   14.32   0.0006
Remainder       34   309.505     9.103

Relative Efficiency, RCB 14.37

Means of Soil for Treatment

Treatment    Mean
CT         119.21
CT-M       112.32
CT-MR      117.08
CT-R       109.80
MT         123.27
MT-M       135.58
MT-MR      121.90
MT-R       124.83
Observations per Mean            6
Standard Error of a Mean    1.4473
Std Error (Diff of 2 Means) 2.0468


LSD All-Pair wise Comparisons Test of Soil for Treatment

Treatment    Mean  Homogeneous Groups
MT-M       135.58  A
MT-R       124.83   B
MT         123.27   BC
MT-MR      121.90   BC
CT         119.21    CD
CT-MR      117.08     D
CT-M       112.32      E
CT-R       109.80      E

Alpha              0.05     Standard Error for Comparison  2.0468
Critical T Value  2.030     Critical Value for Comparison  4.1552
Error term used: Month*Treatment, 35 DF
There are 5 groups (A, B, etc.) in which the means are not significantly
different from one another.
```

Table 19: *LRS Systems Trial season one(2016/17) Analyzed Maize Grain Yield(Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 12:58:28 PM

Randomized Complete Block AOV Table for 2016/17 MAIZE GRAIN

Source	DF	SS	MS	F	P
REPLICATE	3	1661063	553688		
TREATMENT	7	657005	93858	0.55	0.7895
Error	21	3604875	171661		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 1202.0 CV 34.47

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	53594	53594	0.30	0.5888
Remainder	20	3551281	177564		

Relative Efficiency, RCB 1.22

Means of 2016/17 MAIZE GRAIN for TREATMENT

TREATMENT	Mean
1	1214.5
2	1301.5
3	1414.8
4	953.8
5	1210.8
6	1080.8
7	1346.3
8	1093.8

Observations per Mean 4
Standard Error of a Mean 207.16
Std Error (Diff of 2 Means) 292.97

Statistix 9.0 9/6/2018, 12:49:27 PM

LSD All-Pair wise Comparisons Test of 2016/17 MAIZE GRAIN for TREATMENT

TREATMENT	Mean	Homogeneous Groups
3	1414.8	A
7	1346.3	A
2	1301.5	A
1	1214.5	A
5	1210.8	A
8	1093.8	A
6	1080.8	A
4	953.8	A

Alpha 0.05 Standard Error for Comparison 292.97
Critical T Value 2.080 Critical Value for Comparison 609.26
Error term used: REPLICATE*TREATMENT, 21 DF
There are no significant pair wise differences among the means.

Table 20: *LRS Systems Trial season two (2017/18) Analyzed Maize Grain Yield (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 1:02:06 PM

Randomized Complete Block AOV Table for 2017/18 MAIZE GRAIN

Source	DF	SS	MS	F	P
REPLICATE	4	4479923	1119981		
TREATMENT	7	6954849	993550	1.36	0.2750
Error	20	1.460E+07	730216		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 2895.3 CV 29.51

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	202504	202504	0.27	0.6112
Remainder	19	1.440E+07	757991		

Relative Efficiency, RCB 1.05

Means of 2017/18 MAIZE GRAIN for TREATMENT

TREATMENT	N	Mean	SE
1	4	2915.7	471.01
2	4	3156.2	471.01
3	4	3768.7	471.01
4	4	2762.7	471.01
5	4	2127.2	471.01
6	4	2314.4	436.52
7	4	3110.2	471.01
8	4	3007.7	471.01

Statistix 9.0 9/6/2018, 1:02:49 PM

LSD All-Pair wise Comparisons Test of 2017/18 MAIZE GRAIN for TREATMENT

TREATMENT	Mean	Homogeneous Groups
3	3768.7	A
2	3156.2	AB
7	3110.2	AB
8	3007.7	AB
1	2915.7	AB
4	2762.7	AB
6	2314.4	B
5	2127.2	B

Alpha 0.05 Standard Error for Comparison 604.24 TO 659.28
Critical T Value 2.086 Critical Value for Comparison 1260.4 TO 1375.2
Error term used: REPLICATE*TREATMENT, 20 DF
There are 2 groups (A and B) in which the means are not significantly different from one another.

Table 21: *LRS Systems Trial 2016/17 Analyzed Cowpea Grain Yield (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 1:12:57 PM

Randomized Complete Block AOV Table for 2016/17 COWPEA GRAIN

Source	DF	SS	MS	F	P
REPLICATE	3	29856	9951.9		
TREATMENT	7	205801	29400.1	0.33	0.9294
Error	21	1849196	88057.0		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 920.28 CV 32.24

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	115678	115678	1.33	0.2616
Remainder	20	1733518	86676		

Relative Efficiency, RCB 0.91

Means of 2016/17 COWPEA GRAIN for TREATMENT

TREATMENT	Mean
1	1032.5
2	893.0
3	985.5
4	897.0
5	988.0
6	773.8
7	841.0
8	951.5

Observations per Mean 4
Standard Error of a Mean 148.37
Std Error (Diff of 2 Means) 209.83

Statistix 9.0 9/6/2018, 1:20:26 PM

LSD All-Pair wise Comparisons Test of 2016/17 COWPEA GRAIN for TREATMENT

TREATMENT	Mean	Homogeneous Groups
1	1032.5	A
5	988.0	A
3	985.5	A
8	951.5	A
4	897.0	A
2	893.0	A
7	841.0	A
6	773.8	A

Alpha 0.05 Standard Error for Comparison 209.83
Critical T Value 2.080 Critical Value for Comparison 436.36
Error term used: REPLICATE*TREATMENT, 21 DF
There are no significant pair wise differences among the means.

Table 22: *2017/18 Analyzed Cowpea Grain Yield for the Systems Trial at LRS (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 1:30:53 PM

Randomized Complete Block AOV Table for 2017/18 COWPEA GRAIN

Source	DF	SS	MS	F	P
REPLICATE	3	124836	41612.0		
TREATMENT	7	674787	96398.1	4.73	0.0026
Error	21	427939	20378.0		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 477.78 CV 29.88

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	90126	90125.7	5.34	0.0317
Remainder	20	337813	16890.6		

Relative Efficiency, RCB 1.10

Means of 2017/18 COWPEA GRAIN for TREATMENT

TREATMENT	Mean
1	260.25
2	361.50
3	316.75
4	499.25
5	575.00
6	608.25
7	712.00
8	489.25

Observations per Mean 4
Standard Error of a Mean 71.376
Std Error (Diff of 2 Means) 100.94

Statistix 9.0 9/6/2018, 1:24:47 PM

LSD All-Pair wise Comparisons Test of 2017/18 COWPEA GRAIN for TREATMENT

TREATMENT	Mean	Homogeneous Groups
7	712.00	A
6	608.25	AB
5	575.00	AB
4	499.25	BC
8	489.25	BC
2	361.50	CD
3	316.75	CD
1	260.25	D

Alpha 0.05 Standard Error for Comparison 100.94
Critical T Value 2.080 Critical Value for Comparison 209.92
Error term used: REPLICATE*TREATMENT, 21 DF
There are 4 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 23: *Analyzed 2016/17 Maize Grain Yield for the Component Trial at LRS (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 1:54:08 PM

Randomized Complete Block AOV Table for 2016/17 MAIZE GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	1622779	540926		
TREATMENT	7	4177352	596765	2.10	0.0884
Error	21	5954544	283550		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 1669.8 CV 31.89

Relative Efficiency, RCB 1.09

Means of 2016/17 MAIZE GRAIN YIELD for TREATMENT

TREATMENT	N	Mean	SE
1	3	2089.6	312.83
2	4	2160.2	266.25
3	5	1571.5	240.24
4	4	1846.5	266.25
5	4	1937.2	266.25
6	4	1206.7	266.25
7	4	1404.0	266.25
8	4	1142.2	266.25

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Statistix 9.0 9/6/2018, 2:05:58 PM

LSD All-Pair wise Comparisons Test of 2016/17 MAIZE GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
2	2160.3	A
1	2023.5	A
5	1937.3	AB
4	1846.5	ABC
3	1570.0	ABC
7	1404.0	ABC
6	1206.8	BC
8	1142.3	C

Alpha 0.05 Standard Error for Comparison 351.69 TO 369.29
Critical T Value 2.074 Critical Value for Comparison 729.37 TO 765.86
Error term used: Error, 22 DF
There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 24: *2017/18 Analyzed Maize Grain Yield for the LRS Component Trial(Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 2:10:51 PM

Randomized Complete Block AOV Table for 2017/18 MAIZE GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	2851440	950480		
TREATMENT	7	5022946	717564	3.11	0.0206
Error	21	4852484	231071		
Total	31				

Note: SS are marginal (type III) sums of squares

Grand Mean 3161.4 CV 15.21

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	565306	565306	2.64	0.1200
Remainder	20	4287178	214359		

Relative Efficiency, RCB 1.30

Means of 2017/18 MAIZE GRAIN YIELD for TREATMENT

TREATMENT	Mean
1	2899.5
2	3371.8
3	2948.3
4	3852.3
5	2524.0
6	2920.0
7	3225.0
8	3550.8

Observations per Mean 4
Standard Error of a Mean 240.35
Std Error (Diff of 2 Means) 339.90

Statistix 9.0 9/6/2018, 2:12:43 PM

LSD All-Pair wise Comparisons Test of 2017/18 MAIZE GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
4	3852.3	A
8	3550.8	AB
2	3371.8	AB
7	3225.0	ABC
3	2948.3	BC
6	2920.0	BC
1	2899.5	BC
5	2524.0	C

Alpha 0.05 Standard Error for Comparison 339.90
Critical T Value 2.080 Critical Value for Comparison 706.87
Error term used: REPLICATE*TREATMENT, 21 DF
There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 25: *Analyzed 2016/17 Cowpea Grain Yield results for the LRS Component Trial (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 2:23:50 PM

Randomized Complete Block AOV Table for 2016/17 COWPEA GRAIN

Source	DF	SS	MS	F	P
REPLICATE	3	159972	53324		
TREATMENT	3	703799	234600	1.12	0.3923
Error	9	1890386	210043		
Total	15				

Note: SS are marginal (type III) sums of squares

Grand Mean 1149.9 CV 39.85

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	252007	252007	1.23	0.2995
Remainder	8	1638379	204797		

Relative Efficiency, RCB 0.82

Means of 2016/17 COWPEA GRAIN for TREATMENT

TREATMENT	Mean
3	827.0
4	1233.7
7	1135.3
8	1403.8

Observations per Mean 4
Standard Error of a Mean 229.15
Std Error (Diff of 2 Means) 324.07

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Statistix 9.0 9/6/2018, 2:28:01 PM

LSD All-Pair wise Comparisons Test of 2016/17 COWPEA GRAIN for TREATMENT

TREATMENT	Mean	Homogeneous Groups
8	1403.8	A
4	1233.7	A
7	1135.3	A
3	827.0	A

Alpha 0.05 Standard Error for Comparison 324.07
Critical T Value 2.262 Critical Value for Comparison 733.10
Error term used: REPLICATE*TREATMENT, 9 DF
There are no significant pair wise differences among the means.

Table 26: *2017/18 Cowpea Grain Yield analysis results for the Component Trial at LRS (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 2:30:53 PM

Randomized Complete Block AOV Table for 2017/18 COWPEA GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	94545.7	31515.2		
TREATMENT	3	30795.7	10265.2	2.32	0.1442
Error	9	39897.1	4433.0		
Total	15				

Note: SS are marginal (type III) sums of squares

Grand Mean 154.81 CV 43.01

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	14040.0	14040.0	4.34	0.0707
Remainder	8	25857.1	3232.1		

Relative Efficiency, RCB 2.14

Means of 2017/18 COWPEA GRAIN YIELD for TREATMENT

TREATMENT	Mean
3	85.50
4	176.00
7	153.50
8	204.25

Observations per Mean 4
Standard Error of a Mean 33.290
Std Error (Diff of 2 Means) 47.080

Table 27: *MITC Component Analyzed 2016/17 Pearl millet Grain Yield (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 3:18:20 PM

Randomized Complete Block AOV Table for 2016/17 PEARL MILLET GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	348647	116216		
TREATMENT	7	1916318	273760	2.27	0.0496
Error	37	4455113	120408		
Total	47				

Note: SS are marginal (type III) sums of squares

Grand Mean 1417.2 CV 24.48

Relative Efficiency, RCB 1.00

Means of 2016/17 PEARL MILLET GRAIN YIELD for TREATMENT

TREATMENT	N	Mean	SE
1	8	1783.0	122.68
2	8	1369.5	122.68
3	4	1247.0	173.50
4	4	1371.3	173.50
5	8	1520.8	122.68
6	8	1562.0	122.68
7	4	1044.8	173.50
8	4	1439.8	173.50

Statistix 9.0 9/6/2018, 3:22:09 PM

LSD All-Pair wise Comparisons Test of 2016/17 PEARL MILLET GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
1	1783.0	A
6	1562.0	AB
5	1520.8	AB
8	1439.8	ABC
4	1371.3	ABC
2	1369.5	BC
3	1247.0	BC
7	1044.8	C

Alpha 0.05 Standard Error for Comparison 173.50 TO 245.37
Critical T Value 2.026 Critical Value for Comparison 351.54 TO 497.16
Error term used: Error, 37 DF
There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 28: *MITC Component Analyzed 2017/18 Pearl millet Grain Yield (Statistix 9 Analysis output)*

Statistix 9.0 9/6/2018, 3:31:37 PM

Randomized Complete Block AOV Table for 2017/18 PEARL MILLET GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	255082	85027.2		
TREATMENT	7	345188	49312.5	2.04	0.0752
Error	37	892552	24123.0		
Total	47				

Note: SS are marginal (type III) sums of squares

Grand Mean 991.16 CV 15.67

Relative Efficiency, RCB 1.24

Means of 2017/18 PEARL MILLET GRAIN YIELD for TREATMENT

TREATMENT	N	Mean	SE
1	8	980.7	54.912
2	8	1051.0	54.912
3	4	935.0	77.658
4	4	1137.5	77.658
5	8	854.9	54.912
6	8	1009.4	54.912
7	4	889.0	77.658
8	4	1071.8	77.658

Statistix 9.0 9/6/2018, 3:35:12 PM

LSD All-Pair wise Comparisons Test of 2017/18 PEARL MILLET GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
4	1137.5	A
8	1071.8	AB
2	1051.0	AB
6	1009.4	ABC
1	980.7	ABC
3	935.0	ABC
7	889.0	BC
5	854.9	C

Alpha 0.05 Standard Error for Comparison 77.658 TO 109.82
Critical T Value 2.026 Critical Value for Comparison 157.35 TO 222.53
Error term used: Error, 37 DF
There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 29: *MITC Component Analyzed 2016/17 Cowpea Grain Yield (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 3:02:07 PM

Randomized Complete Block AOV Table for 2016/17 COWPEA GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	846009	282003		
TREATMENT	3	634611	211537	3.38	0.0677
Error	9	562451	62495		
Total	15				

Note: SS are marginal (type III) sums of squares

Grand Mean 1081.9 CV 23.11

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	25243	25243.0	0.38	0.5568
Remainder	8	537208	67150.9		

Relative Efficiency, RCB 1.64

Means of 2016/17 COWPEA GRAIN YIELD for TREATMENT

TREATMENT	Mean
3	1398.5
4	1105.0
7	923.0
8	901.2

Observations per Mean 4
Standard Error of a Mean 124.99
Std Error (Diff of 2 Means) 176.77

Statistix 9.0 9/6/2018, 3:03:38 PM

LSD All-Pair wise Comparisons Test of 2016/17 COWPEA GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
3	1398.5	A
4	1105.0	AB
7	923.0	B
8	901.2	B

Alpha 0.05 Standard Error for Comparison 176.77
Critical T Value 2.262 Critical Value for Comparison 399.88
Error term used: REPLICATE*TREATMENT, 9 DF
There are 2 groups (A and B) in which the means are not significantly different from one another.

Table 30: *MITC Component Analyzed 2017/18 Cowpea Grain Yield (Statistix 9 Analysis Output)*

Statistix 9.0 9/6/2018, 2:53:51 PM

Randomized Complete Block AOV Table for 2017/18 COWPEA GRAIN YIELD

Source	DF	SS	MS	F	P
REPLICATE	3	33402.5	11134.2		
TREATMENT	3	22549.5	7516.5	4.37	0.0370
Error	9	15486.0	1720.7		
Total	15				

Note: SS are marginal (type III) sums of squares

Grand Mean 424.50 CV 9.77

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	391.2	391.18	0.21	0.6610
Remainder	8	15094.8	1886.85		

Relative Efficiency, RCB 2.01

Means of 2017/18 COWPEA GRAIN YIELD for TREATMENT

TREATMENT	Mean
3	446.25
4	361.50
7	458.25
8	432.00

Observations per Mean 4
Standard Error of a Mean 20.740
Std Error (Diff of 2 Means) 29.331

Statistix 9.0 9/6/2018, 2:55:05 PM

LSD All-Pair wise Comparisons Test of 2017/18 COWPEA GRAIN YIELD for TREATMENT

TREATMENT	Mean	Homogeneous Groups
7	458.25	A
3	446.25	A
8	432.00	A
4	361.50	B

Alpha 0.05 Standard Error for Comparison 29.331
Critical T Value 2.262 Critical Value for Comparison 66.352
Error term used: REPLICATE*TREATMENT, 9 DF
There are 2 groups (A and B) in which the means are not significantly different from one another.