EFFECT OF RESIDUE RETENTION STRATEGIES ON MAIZE PRODUCTIVITY IN ZIMBABWE

A dissertation submitted in partial fulfilment of the requirements for the Master of Science Degree in Food Security and Sustainable Agriculture Production

Bindura University of Science Education

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DECLARATION

I hereby declare that the research project entitled ‘**Effect of different residue retention strategies on maize cropping system productivity in Zimbabwe’** submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of an original work done by me under the guidance and supervision of **Ms Masona** and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science Degree in Food Security and Sustainable Agriculture. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree of diploma.

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DEDICATION

To my parents, my husband Tarirai and my lovely daughter, Elsa Anashe.

ACKNOWLEDGEMENTS

To my supervisors, Ms C. Masona and Dr. C. Thierfelder thank you so much for all the support, guidance, motivation and patience you have all displayed during the course of this work. Exceptional thanks goes to the International Maize and Wheat Improvement Centre (CIMMYT) under the CGIAR Research Program (CRP) MAIZE for logistically supporting this study and all costs incurred during the study through Dr C. Thierfelder.

Special thanks go to Mr Sign Phiri and Mr Herbert Chipara for technical support to make the research a success. I also would like to extend my gratitude to field staff at University of Zimbabwe farm and Domboshava Training Centre for their limitless effort during the course of the research.

I would like to thank the Muoni family who has been supportive since the beginning of the study as well as at this end. To all my friends especially Lena Majoni, I thank you.

ABSTRACT

Most smallholder farmers in Zimbabwe rely on rainfall for crop production. However, the changes in the climate results in erratic rainfall patterns which makes most farmers to be food insecure. Efforts have been made to improve agronomic practices through no till practices and retention of crop residues in the field. However, most farmers practice conventional tillage for land preparation, weed management, incorporating manure and sowing crops. This study aimed at investigating the effects of tillage practices and crop residue retention strategies on maize production in Zimbabwe. The study involved an experiment laid out as a randomised complete block design with two main treatments (no till and conventional tillage) and four sub-treatments (no residues, 3t ha^{-1} maize residues, 3t ha^{-1} pigeon pea residues and 6 t ha^{-1} maize crop residues). Data collected included water infiltration, soil macrofauna, leaf chlorophyll content, maize biomass and grain yield. The results show that crop residue retention strategies have a significant effect ($p < 0.05$) on water infiltration and soil macrofauna. Tillage systems had a significant effect ($p < 0.05$) on leaf chlorophyll content and grain yields. Water infiltration was also influenced by soil types which were distinct at the study sites. The delayed gratification which occurs in no till systems results in low maize grain and stover??? yield at the beginning of adopting no till systems. However, improvement in water infiltration and soil macrofauna helps improve maize productivity in the long term thus improving food security in smallholder farms. Small holder farmers should practice no till farming and retain crop residues in their fields to improve maize productivity in the face of climate change.

Keywords: rainfed, smallholder farmers, infiltration, chlorophyll, yield

LIST OF ACRONYMS AND ABBREVIATIONS

C	carbon
C/N ratio	carbon to nitrogen ratio
CA	conservation agriculture
DTC	Domboshava Training Centre
FAO	Food and Agriculture Organization of the United nations
Ha	hectare
N	nitrogen
SOC	soil organic carbon
SSA	sub-Saharan Africa
TLU	tropical livestock units
UZ	University of Zimbabwe farm

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The majority of smallholder farmers in sub-Sahara Africa (SSA) are food insecure due to various reasons that include erratic rainfall patterns, low input use, poor soil fertility status and high pressure on land due to rapid population increase (Serdeczny et al., 2017; Vanlauwe et al., 2015). Population growth is projected at 2.7% per annum in SSA which will increase the demand for food in the region (Alexandratos and Bruinsma, 2012). Most of the food expected to feed the growing population is produced in rainfed smallholder farming systems. However, most farmers practice conventional tillage which is often accompanied by removal or burning of crop residues from the fields hence reduced soil organic matter (Balesdent et al., 2000). These farming methods practiced by smallholder farmers destroy the soil structure and reduce the soil biological activities which results in low crop stover and grain yields (Mhlanga et al., 2020; Mashavakure et al., 2019; Muoni et al., 2019). Crop yield per unit area in SSA is projected to decrease from 3 % per annum to 1.9 % per annum during the 1987-2050 period (Alexandratos and Bruinsma, 2012).

In southern Africa, farmers mainly practice integrated crop-livestock farming.ommon crops include cereals (such as maize – *Zea mays* L and sorghum – *Sorghum bicolor* L. Moench) and grain legumes (such as common bean – *Phaseolus vulgaris* L., groundnut – *Arachis hypogaea* L. and bambara nuts – *Vigna subterranea* L. Verdc.) (Garrity et al., 2012). Most farmers have low tropical livestock units (TLU) and the common livestock kept include cattle, sheep, goats and poultry (Garrity et al., 2012). Although farmers practice integrated crop-livestock systems, the complimentary benefits are barely achieved due to low biomass produced and less manure from livestock. Hence, the challenge of food insecurity remains key in southern Africa.

Conservation agriculture (CA) defined as a cropping system based on three principles; maintenance of permanent soil cover, minimal soil disturbance, and diverse crop rotations/interactions (FAO, 2010) has been widely recommended to address food insecurity in southern Africa. Conservation agriculture has several benefits which include improved and stable crop yield, improved soil and water conservation, increased soil biological activity and improved soil fertility and agronomic use efficiency among other benefits. For farmers to achieve all these benefits they should practice all the three principles and good agronomic practices (Thierfelder et al., 2018; 2015). Although several benefits of CA have been documented, farmers face several challenges associated with change in management of crops. These challenges include increase in perennial weeds which are difficult to control, lack of technical knowledge e.g. use of direct seeders for sowing crops, and attaining adequate quantities of crop residues to retain in the field (Mazvimavi, 2010; Mhlanga et al., 2015).

Maintenance of permanent soil cover is commonly attained through maize crop residues in southern Africa and at least 30% residue cover is the recommended level (Kassam et al., 2009). Provision of soil cover reduce water evaporation and promotes water infiltration which results in high soil moisture retention (Bombino et al., 2019). Also, the crop residues reduce the impact of raindrops and velocity of rainfall runoff thus reduce soil loss from arable lands (Thierfelder and Wall, 2009). Also retention of crop residues increases soil organic matter (e.g. Huo et al., 2017), increase earthworms and termites (e.g. Muoni et al., 2019), smoother weeds through allelopathy (Mandumbu et al., 2013; Rugare et al., 2019) and increases carbon sequestration (e.g. O'Dell et al., 2020). However, there is high competition for crop residues in smallholder farms. Farmers often prefer to use them to feed livestock and as fuel (Duncan et al., 2016) and there is often insufficient quantities to meet this demand (Mupangwa et al., 2016).

To compensate for the deficit of crop residues some research has recommended importation of non-crop residues including thatch grass (*Hyparrhenia filipendula* (L.) Stapf.) or leaf litter from nearby ecosystems such as forests and grazing lands. This has been successfully tested in Zimbabwe by Mupangwa et al., (2016). However, use of crop residues with high lignin content and carbon (C) to nitrogen (N) ratio (C/N ratio), including maize residues, poses nitrogen lock-up problems (Gentile et al., 2011). This is because the decomposition of these residues is done by microbes that also require nitrogen for their growth. Thus microbes require more nitrogen to break residues with high C/N ratio, and they use the readily available N that should be used by crops (Craine et al., 2007).

Different residues retention strategies that may help reduce nitrogen lock up problems, increase soil carbon pool (Cheesman, 2015), provide ground cover for most of the cropping season (e.g. Sakala et al., 2000), and enhance biological activities that improve soil fertility (Mashavakure et al., 2019) have been recommended. Long-term residue retention strategies are crucial for maintaining soil phosphorus (P) and soil organic carbon (SOC) (Kushwah et al., 2016) and use of legume residues that have low C/N is recommended. Salahin et al. (2017) suggested that increased quantity of crop residues retained with minimum tillage practices improved soil properties and grain yield. Nascente *et al*. (2013) crop points out that residue retention in different farming systems may also influence the soil fauna community by modifying the soil environment bio-chemically and physically.

1.2 Problem Statement

Land degradation continues to worsen over the years due to poor farming methods and this has affected smallholder farmers' livelihoods whose livelihoods depend on agriculture. Most farmers burn or remove crop residues during land preparation and this reduces soil organic matter content. To meet the food demands of the growing population and address land degradation, sustainable agriculture practices including CA has been widely recommended in Zimbabwe. Among the key principles of CA is the maintenance of permanent soil cover commonly practiced by using maize residues by farmers who have adopted it. However, the quantity of biomass produced by smallholder farmers is usually insufficient to fulfil fuel, livestock feed and retaining in the field requirements. Most soils in Zimbabwe have low N (Jones et al., 2013), hence N lock-up is high when crop residues with high C/N ratio are used. This reduces crop yields obtained by farmers. Furthermore, for residues to decompose they should be in contact with the soil but in CA systems they are retained at the soil surface.

1.3 Justification

Retaining crop residues in smallholder farms is crucial to improve soil quality and crop productivity (Kodzwa et al., 2020). Retention of crop residues increases infiltration rate, reducing runoff and evaporation hence maintaining the soil water content suitable for plant growth (Mupangwa and Thierfelder, 2014). Crop residues promote macrofauna densities which are important contributors of soil health (Nhamo, 2007). Crop residues help in maintaining good structure and organic matter levels in the soil.

1.4 Objectives

1.4.1 Main objective

The main objective of this study was to determine the effect of different residue retention strategies on water infiltration, soil macro-organisms and maize productivity in a maize-based agriculture system in Zimbabwe.

1.4.2 Specific Objectives

- To evaluate the effects of different residue retention strategies on water infiltration under maize cropping systems in Zimbabwe.
- To determine the effect of different residue retention strategies on the density of soil macro fauna in maize production systems
- To assess the effects of different residue retention strategies on chlorophyll content during the cropping season under CA systems in Zimbabwe.
- To evaluate the effect of different residue retention strategies on maize grain and stover yield under CA in Zimbabwe.

1.5 Research Hypotheses

- Different residue retention strategies improve soil aggregation that increases water infiltration
- Residue retention promotes soil macro fauna activities in maize production systems.
- Retention of crop residues in maize production systems influences N flows which has a direct contribution to crop chlorophyll content,
- Different residues retention strategies improve soil fertility build up, water infiltration and moisture retention that enhance maize productivity under CA in Zimbabwe.

1.6 Outline of Thesis

The thesis consists of six chapters. Chapter 1 discusses the overall background, importance of crop residues in maize cropping systems and objectives of the study and hypotheses. Chapter 2 is a literature review on previous studies related to this study. Chapter 3 describes the research methods and sites used by the researcher including all the procedures and materials pertaining to crop management, experimental designs, description of sites and data collection and analyses. Chapters 4 and 5 are the research based and results obtained from the study and are represented in form of tables, and graphs. These chapters also include discussion of the study results and comparison with other researchers’ findings. Chapter 6 is the summary of the study, conclusions and recommendations drawn from chapter 4 and 5 findings.

1.7 References

Alexandratos, N., Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper FAO, Rome.

Balesdent, J., Chenu, C., Balabane, M., 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil and Tillage Research 53, 215–230. https://doi.org/10.1016/S0167-1987(99)00107-5

Bombino, G., Denisi, P., Gómez, J.A., Zema, D.A., 2019. Water infiltration and surface runoff in steep clayey soils of olive groves under different management practices. Water 11, 240.

Cheesman, S., 2015. Finding the truth in wishful thinking: an on-farm study on maize-based conservation agriculture systems in Southern Africa.

Craine, J.M., Morrow, C., Fierer, N., 2007. Microbial nitrogen limitation increases decomposition. Ecology 88, 2105–2113.

Duncan, A.J., Bachewe, F., Mekonnen, K., Valbuena, D., Rachier, G., Lule, D., Bahta, M., Erenstein, O., 2016. Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. Agriculture, Ecosystems & Environment 228, 101–110. https://doi.org/10.1016/j.agee.2016.05.011

FAO, 2010. The Status of Conservation Agriculture in Southern Africa: Challenges and Opportunities for Expansion. REOSA Technical Brief 03. http://www.fao.org/ag/ca/doc/FAO_REOSA_Technical_Brief3.pdf

Garrity, D., Dixon, J., Boffa, J.-M., 2012. Understanding African Farming Systems: Science and Policy Implications. Presented at the Food security in Africa: Bridging research and practice.

Gentile, R., Vanlauwe, B., Chivenge, P., Six, J., 2011. Trade-offs between the short-and long-term effects of residue quality on soil C and N dynamics. Plant and Soil 338, 159–169.

Huo, L., Pang, H., Zhao, Y., Wang, J., Lu, C., Li, Y., 2017. Buried straw layer plus plastic mulching improves soil organic carbon fractions in an arid saline soil from Northwest China. Soil and Tillage Research 165, 286–293.

Jones, A., Breuning-Madsen, H., Brossard, A., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R., 2013. Soil atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009. The spread of Conservation Agriculture: justification, sustainability and uptake¹. International Journal of Agricultural Sustainability 7, 292–320. https://doi.org/10.3763/ijas.2009.0477

Kodzwa, J.J., Gotosa, J., Nyamangara, J., 2020. Mulching is the most important of the three conservation agriculture principles in increasing crop yield in the short term, under sub humid tropical conditions in Zimbabwe. Soil and Tillage Research 197, 104515. https://doi.org/10.1016/j.still.2019.104515

Kushwah, S., Reddy, D.D., Somasundaram, J., Srivastava, S., Khamparia, R., 2016. Crop residue retention and nutrient management practices on stratification of phosphorus and soil organic carbon in the soybean–wheat system in vertisols of central India. Communications in Soil Science and Plant Analysis 47, 2387–2395.

Mandumbu, R., Karavina, C., Muoni, T., 2013. Effect of temperature, residue level and burial depth on germination of two weed: Implication to conservation agriculture. Presented at the African Crop Science Conference Proceedings, pp. 97–100.

Mashavakure, N., Mashingaidze, A.B., Musundire, R., Nhamo, N., Gandiwa, E., Thierfelder, C., Muposhi, V.K., 2019. Soil dwelling beetle community response to tillage, fertilizer and weeding intensity in a sub-humid environment in Zimbabwe. Applied Soil Ecology 135, 120–128. https://doi.org/10.1016/j.apsoil.2018.12.001

Mazvimavi, K., 2010. Socio-Economic Analysis of Conservation Agriculture in Southern Africa.

Mhlanga, B., Cheesman, S., Maasdorp, B., Muoni, T., Mabasa, S., Mangosho, E., Thierfelder, C., 2015. Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. Crop Protection 69, 1–8.

Mhlanga, B., Muoni, T., Mashavakure, N., Mudadirwa, D., Mulenga, R., Sitali, M., Thierfelder, C., 2020. Friends or foes? Population dynamics of beneficial and detrimental aerial arthropods under Conservation Agriculture. Biological Control 148, 104312. https://doi.org/10.1016/j.biocontrol.2020.104312

Muoni, T., Mhlanga, B., Forkman, J., Sitali, M., Thierfelder, C., 2019. Tillage and crop rotations enhance populations of earthworms, termites, dung beetles and centipedes: evidence from a long-term trial in Zambia. The Journal of Agricultural Science 1–11.

Mupangwa, W., Nyagumbo, I., Mutsamba, E., 2016. Effect of different mulching materials on maize growth and yield in conservation agriculture systems of sub-humid Zimbabwe. AIMS agriculture and food.

Mupangwa, W., Thierfelder, C., 2014. Intensification of conservation agriculture systems for increased livestock feed and maize production in Zimbabwe. International Journal of Agricultural Sustainability 12, 425–439. https://doi.org/10.1080/14735903.2013.859836

Nascente, A.S., Crusciol, C.A.C., Cobucci, T., 2013. The no-tillage system and cover crops—Alternatives to increase upland rice yields. European Journal of Agronomy 45, 124–131. https://doi.org/10.1016/j.eja.2012.09.004

Nhamo, N., 2007. The contribution of different fauna communities to improved soil health: a case of Zimbabwean soils under conservation agriculture. ZEF.

O'Dell, D., Eash, N.S., Hicks, B.B., Oetting, J.N., Sauer, T.J., Lambert, D.M., Thierfelder, C., Muoni, T., Logan, J., Zahn, J.A., 2020. Conservation agriculture as a climate change mitigation strategy in Zimbabwe. International Journal of Agricultural Sustainability 1–16.

Rugare, J.T., Pieterse, P.J., Mabasa, S., 2019. Effect of short-term maize–cover crop rotations on weed emergence, biomass and species composition under conservation agriculture. South African Journal of Plant and Soil 36, 329–337.

Sakala, W.D., Cadisch, G., Giller, K.E., 2000. Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. Soil biology and biochemistry 32, 679–688.

Salahin, N., Alam, K., Mondol, A.T.M.A.I., Islam, M.S., Rashid, M.H., Hoque, M.A., 2017. Effect of tillage and residue retention on soil properties and crop yields in Wheat-Mungbean-Rice Crop rotation under subtropical humid climate. Open Journal of Soil Science 7, 1.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., Reinhardt, J., 2017. Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. Reg Environ Change 17, 1585–1600. https://doi.org/10.1007/s10113-015-0910-2

Thierfelder, C., Baudron, F., Setimela, P., Nyagumbo, I., Mupangwa, W., Mhlanga, B., Lee, N., Gérard, B., 2018. Complementary practices supporting conservation agriculture in southern Africa. A review. Agronomy for Sustainable Development 38, 16. https://doi.org/10.1007/s13593-018-0492-8

Thierfelder, C., Rusinamhodzi, L., Ngwira, A.R., Mupangwa, W., Nyagumbo, I., Kassie, G.T., Cairns, J.E., 2015. Conservation agriculture in Southern Africa: Advances in knowledge. Renewable Agriculture and Food Systems.

Thierfelder, C., Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105, 217–227. https://doi.org/10.1016/j.still.2009.07.007

Vanlauwe, B., Six, J., Sanginga, N., Adesina, A.A., 2015. Soil fertility decline at the base of rural poverty in sub-Saharan Africa. Nature Plants 1, 15101.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Smallholder farmers in southern Africa receive rainfall in a bimodal pattern and the majority (approximately 95%) depend on natural rainfall for farming (Rosegrant et al., 2009). This results in moisture scarcity problems which are further worsened by unreliable rainfall patterns, high drought frequency, prolonged mid-season dry spells and increase in temperature (Girvetz et al., 2019; Rosegrant et al., 2009). Challenges with access to agricultural inputs including fertilisers, herbicides and equipment are very high. Most families depend on family labour to get tasks done, hence they face challenges with establishing crops with first effective rains and attaining critical weed free period (Takane, 2008). For food security reasons, majority of farmers continuously grow maize which affects productivity due to pest and disease pressure (Cheesman, 2015).

For farming activities including land preparation, sowing, weed management and incorporating manure, farmers practice conventional ploughing using hand hoes or mouldboard plough. Mouldboard ploughs are often used by farmers with access to draught animals. Ploughing the land has several advantages which includes improving air circulation for roots respiration, roots can penetrate deeper soil depth however its disadvantages are more. Ploughing the land loosens the soil which increases its vulnerability to wind and water erosion. Ploughing at the same depth creates a soil pan which impedes root penetration and also increases the chances for water logging. Furthermore, ploughing brings the otherwise buried weed seeds to the surface where they can germinate and increase weed pressure in smallholder farms.

All these challenges mentioned make it difficult for farmers to produce adequate food to meet their demands before they reach the next crop harvest. Thus, conservation agriculture has been studied extensively in southern Africa.

2.2 The concept of conservation agriculture.

Conservation agriculture is a system that strives to conserve, improve and advocate for sustainable use of available natural resources (Shaxson et al., 2008). Conservation agriculture provides environmental benefits which are of global importance. Hobbs *et al*., (2006), supports that CA is defined by the three key principles which are minimal soil disturbances, maintenance of a permanent soil cover and diverse crop rotations or crop interactions.

2.21 Minimum soil disturbance

Minimal soil disturbance is a principle which governs conservation agriculture. No-till farming has caught on as a process that can save soil organic matter levels for a long period and still allow the soil to be productive for long periods (Shaxson et al., 2008). According to Dumanski *et al.,* (2006), in no till farming system, crops are planted in previously undisturbed soils, thus the soil remains covered by plant residues from previous crops. No-till practices have agro-ecological benefits which include the improvement of soil fertility and the maintenance of the soil profile.

In southern Africa minimum soil disturbance is done using hand hoes to make planting basins and shallow planting fallows (or referred to as rip lines) and animal powered options including ripper and direct seeders.

Planting basins

These are small pits that can be dug with hand hoes without having to plough the whole field. They are dug from July through to October in the same position annually and the recommended dimensions are 15cm (deep) × 15cm (long) × 15cm (wide) (Mupangwa et al., 2007; Twomlow et al., 2008). The use of planting basins which are constructed during the dry seasons (July – October) enables farmers to sow their crops after receiving first effective rains - when the basins have captured rainwater and drained naturally (Harford and Le Breton, 2009). Planting basins allow precision application of both organic and inorganic fertilizer as it is applied directly into the pit and not broadcasted.

Shallow planting fallows

Harford and Le Breton (2009) stated shallow planting fallows are done for small grain crops and legumes. These are done using hand hoe and they are done between July and October and the fallows are 5-10cm wide.

Animal powered options

Farmers that have access to draught power and mouldboard plough may choose to use ripper tines attached to the plough which makes rip lines. The rip lines are opened at different spacing depending on the crop to be established. The available soil fertility amendments such as basal dressing can then be added to each rip line before planting. Ripper tine is fitted to the plough frame and opened to 15cm depth. Another animal powered options is the direct seeders which allows farmers to make rip lines, drop seed, apply fertilizer and cover the soil at the same time (Thierfelder and Wall, 2010) . Although this is a better option than ripper lines and making basins, the direct seeders are not readily available at Zimbabwe markets.

2.2.2 Diverse crop rotations/interactions

Diverse crop rotation/ crop interactions is another key principle for CA. Crop rotations promote biological activity, root growth and improves soil fertility and soil structure (Mupangwa and Thierfelder, 2014). It is an effective tool for managing pest and prevents the buildup of pathogens thus decreasing pesticide use and reduce water pollution (Mashingaidze et al., 2009). Crop rotation optimize soil nutrient cycling, where leguminous plants are part of crop rotation sequence, significant amount of energy intensive and expensive mineral fertilizer can be replaced by natural fixation (Mashingaidze et al., 2009)

2.2.3 Maintenance of permanent soil cover

Permanent soil coil cover is the other principle of CA. Provision of permanent soil cover is a key requirement for CA and at least 30% residue cover is recommended at the time of seeding (Kassam et al., 2012). In CA different residues are used as mulching and they act as a permanent soil cover and these include *Zea mays* (maize Stover), *Hyperrhenia* (thatch grass), *Uapaca kirkian*a (Muzhanje) leaf litter, *Crotalaria grahamiana* and *Tephrosia vogelli.* Mhlanga and Muoni, (2014), suggests that mulch provides a variety of ecological benefits when used correctly. According to Lestrelin *et al*., (2012), many materials are used as mulches to retain soil moisture, regulate soil temperature, suppress weed growth, for aesthetics and prevent soil erosion. Giller et al., (2009) points out that while benefits of CA are most directly attributed to the mulch of crop residues retained in the field, limited availability of crop residues is a major constraint for adoption of CA practices. Fahad *et al*., (2013) notes that towards the beginning of the growing season, mulches serve initially to warm the soil by helping it retain heat which is lost during the night. This allows early seeding and transplanting of certain crops, and encourages faster growth. As the season progresses, mulch stabilizes the soil temperature and moisture, and prevents the growing of weeds from seeds. Mulch forms a layer between the soil and the atmosphere which prevents direct sunlight from reaching the soil surface, thus reducing evaporation. Mupangwa and Thierfelder, (2014) notes that mulch controls weed growth by smothering seedlings, prevents daylight which helps foster germination from reaching weed seeds, and prevents air-borne seeds from taking hold in the soil surface.

Derpsch, (2002) suggests that benefits of CA take a long time to be noticed. Conservation Agriculture systems have been successfully adapted to local conditions by the commercial farmers in America and Australia, whilst adoption by smallholder farmers has lagged behind. Mazvimavi et al., (2010) notes that labour and land sizes still remain the major challenge that limits effective uptake of conservation agriculture by small holder farmers in Zimbabwe. Critical constraints to adoption appear to be competing uses for crop residues, increased labour demand for weeding, and lack of access to, and use of external inputs (Giller *et al.*, 2009).

2.3 Crop residue management and benefits of using crop residues

Most smallholder farmers in southern Africa practices different crop residue retention strategies which include burning of crop residue, removal of crop residues for livestock feed and incorporation of crop residues which affect soil organic matter content (Duncan et al., 2016; Rusinamhodzi et al., 2015). Application of crop residues in fields promote physical, chemical and biological attributes of soil health in agricultural system (Kumar and Goh, 2000; Turmel et al., 2015). When used as surface mulch, crop residues improves soil structural properties by increasing soil organic matter concentrations which increases water retention capacity of the soil (Blanco-Canqui and Lal, 2009). Bayer et al., (2000) points out that the quantity of residue addition by cropping systems can affect soil organic matter accretion in degraded soils. The rate of soil organic matter accumulation depends largely on the quantity and quality of organic matter input (Kumar and Goh, 2000). Crop residues which are carbon sinks, constitute 40-46% C and provide uncountable ecosystem services including reduction in soil erosion, improvement in soil physical and biological properties thus increasing agronomic production (Blanco-Canqui and Lal, 2009).

Different crop residues have different decomposition rates and this affects nutrient availability for plant uptake during the cropping season (Mhlanga et al., 2015). The peak of nutrient release from organic matter should synchronize with crop growth stages which require more nutrients, for it to be beneficial to crops. Crop residues with both large C: N ratios and lignin contents such as cereal straw and grasses generally favor N immobilization, organic matter accumulation and humus formation, with increased potential for improved soil structure development (Craine et al., 2007; Huo et al., 2017).

It can be noted that in order to maintain nutrient cycling system in the soil the rate of organic matter addition from crop residues, manure and any other sources must equal the rate of decomposition. There are different plant residue management practices in different places under different agro-ecological zones (Shittu and Fasina, 2006). Crop livestock competition for crop residues can be solved by using other types of residues such as leaf litter, thatch grass and legume residues not palatable for livestock. Removal of crop residues in the fields results in the decrease in organic matter supply.

2.4 The quality of crop residues and decomposition

Mhlanga *et al*., (2015) points out that decomposition of different mulching materials is affected by the composition of the mulch. The C/N ratio of different mulching materials affect decomposition in that materials with high C:N ratios decompose at slower rates compared to materials with low C/N ratio which decompose faster (Burgess et al., 2002). The lignin content could have also a significant effect on the decomposition of mulching materials. Karberg *et al*., (2008) suggests that crop residues containing high concentration of labile compounds for example sugars, amino acids tend to decompose rapidly because these compounds can be readily metabolized by soil microorganisms or leached. Tissues in different mulching materials also have a significant effect on the weight loss of different mulching materials (Goldsmith and Carter, 1981). Leguminous crop residue has soft tissues which make it easy for microbes and termites to act on, whilst maize stover has hard tissues that make it difficult for soil macro fauna to feed on. Thierfelder et al., (2013) suggests that leaf litter leaves are easier to decompose than other residues used because of the finer tissues they have that means they are soft to be worked on by the microbes to form humus.

2.5 References

Bayer, C., Mielniczuk, J., Amado, T.J.C., Martin-Neto, L., Fernandes, S.V., 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. Soil Tillage Res. 54, 101–109. https://doi.org/10.1016/S0167-1987(00)00090-8

Blanco-Canqui, H., Lal, R., 2009. Crop Residue Removal Impacts on Soil Productivity and Environmental Quality. Crit. Rev. Plant Sci. 28, 139–163. https://doi.org/10.1080/07352680902776507

Burgess, M.S., Mehuys, G.R., Madramootoo, C.A., 2002. Decomposition of grain-corn residues (Zea mays L.): A litterbag study under three tillage systems. Can. J. Soil Sci. 82, 127–138.

Cheesman, S., 2015. Finding the truth in wishful thinking: an on-farm study on maize-based conservation agriculture systems in Southern Africa.

Craine, J.M., Morrow, C., Fierer, N., 2007. Microbial nitrogen limitation increases decomposition. Ecology 88, 2105–2113.

Dumanski, J., Peiretti, R., Benites, J.R., McGarry, D., Pieri, C., 2006. The paradigm of conservation agriculture. Proc World Assoc Soil Water Conserv P 1, 58–64.

Duncan, A.J., Bachewe, F., Mekonnen, K., Valbuena, D., Rachier, G., Lule, D., Bahta, M., Erenstein, O., 2016. Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. Agric. Ecosyst. Environ. 228, 101–110. https://doi.org/10.1016/j.agee.2016.05.011

Fahad, S., Nie, L., Rahman, A., Chen, C., Wu, C., Saud, S., Huang, J., 2013. Comparative Efficacy of Different Herbicides for Weed Management and Yield Attributes in Wheat. Am. J. Plant Sci. 04, 1241–1245. https://doi.org/10.4236/ajps.2013.46152

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114, 23–34. https://doi.org/10.1016/j.fcr.2009.06.017

Girvetz, E., Ramirez-Villegas, J., Claessens, L., Lamanna, C., Navarro-Racines, C., Nowak, A., Thornton, P., Rosenstock, T.S., 2019. Future Climate Projections in Africa: Where Are We Headed?, in: Rosenstock, T.S., Nowak, A., Girvetz, E. (Eds.), The Climate-Smart Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future. Springer International Publishing, Cham, pp. 15–27. https://doi.org/10.1007/978-3-319-92798-5_2

Harford, N., Le Breton, J., 2009. Farming for the future: A guide to conservation agriculture in Zimbabwe.

Hobbs, P., Gupta, R., Meisner, C., 2006. Conservation agriculture and its applications in South Asia. Biol. Approaches Sustain. Soil Syst. Taylor Francis Boca Raton.

Huo, L., Pang, H., Zhao, Y., Wang, J., Lu, C., Li, Y., 2017. Buried straw layer plus plastic mulching improves soil organic carbon fractions in an arid saline soil from Northwest China. Soil Tillage Res. 165, 286–293.

Karberg, N.J., Scott, N.A., Giardina, C.P., 2008. Methods for estimating litter decomposition, in: Field Measurements for Forest Carbon Monitoring. Springer, pp. 103–111.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J., Serraj, R., 2012. Conservation agriculture in the dry Mediterranean climate. Field Crops Res. 132, 7–17. https://doi.org/10.1016/j.fcr.2012.02.023

Kumar, K., Goh, K.M., 2000. CROPRESIDUESAND MANAGEMENT PRACTICEES:FFECTSON SOIL QUALITYS,OILNITROGEN DYNAMICSC, ROPYIELD, AND NITROGERNECOVERY. Soil Plant Ecol. Sci. Div. 68, 1–123.

Lestrelin, G., Quoc, H.T., Jullien, F., Rattanatray, B., Khamxaykhay, C., Tivet, F., 2012. Conservation agriculture in Laos: Diffusion and determinants for adoption of direct seeding mulch-based cropping systems in smallholder agriculture. Renew. Agric. Food Syst. 27, 81–92. https://doi.org/10.1017/S174217051100055X

Mashingaidze, N., Twomlow, S.J., Hove, L., 2009. Crop and weed responses to residue retention and method of weeding in first two years of a hoe-based minimum tillage system in semi-arid Zimbabwe. Jounal SAT Agric. Res. 7, 1–11.

Mazvimavi, K., Ndlovu, P.V., Nyathi, P., Minde, I.J., 2010. Conservation agriculture practices and adoption by smallholder farmers in Zimbabwe, in: Poster Presented at 3rd AAAE Conference. pp. 19–23.

Mhlanga, B, Cheesman, S., Maasdorp, B., Muoni, T., Mabasa, S., Mangosho, E., Thierfelder, C., 2015. Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. Crop Prot. 69, 1–8.

Mhlanga, Blessing, Cheesman, S., Maasdorp, B., Mupangwa, W., Thierfelder, C., 2015. Contribution of Cover Crops to the Productivity of Maize-Based Conservation Agriculture Systems in Zimbabwe. Crop Sci. 55, 1791–1805. https://doi.org/10.2135/cropsci2014.11.0796

Mhlanga, B., Muoni, T., 2014. Crop Residue Management in Conservation Agriculture Systems in Zimbabwe Smallholder Farming Sector: Importance, Management Challenges and Possible Solutions. Asian J. Agric. Rural Dev. 333–340.

Mupangwa, W., Thierfelder, C., 2014. Intensification of conservation agriculture systems for increased livestock feed and maize production in Zimbabwe. Int. J. Agric. Sustain. 12, 425–439. https://doi.org/10.1080/14735903.2013.859836

Mupangwa, W., Twomlow, S., Walker, S., Hove, L., 2007. Effect of minimum tillage and mulching on maize (Zea mays L.) yield and water content of clayey and sandy soils. Phys. Chem. Earth Parts ABC 32, 1127–1134.

Rosegrant, M.W., Ringler, C., De Jong, Ij., 2009. Irrigation: tapping potential. International Bank for Reconstruction and Development/The World Bank.

Rusinamhodzi, L., van Wijk, M.T., Corbeels, M., Rufino, M.C., Giller, K.E., 2015. Maize crop residue uses and trade-offs on smallholder crop-livestock farms in Zimbabwe: Economic implications of intensification. Agric. Ecosyst. Environ. 214, 31–45.

Shaxson, F., Kassam, A.H., Friedrich, T., Boddey, B., Adekunle, A., 2008. Underpinning conservation agriculture's benefits: the roots of soil health and function, in: Main Background Document for the Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health. Presented at the Workshop on investing in sustainable crop intensification, Rome, Italy, pp. 22–24.

Takane, T., 2008. Labor use in smallholder agriculture in Malawi: Six village case studies.

Thierfelder, C., Mwila, M., Rusinamhodzi, L., 2013. Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity. Soil Tillage Res. 126, 246–258. https://doi.org/10.1016/j.still.2012.09.002

Thierfelder, C., Wall, P.C., 2010. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. Journal of Crop Improvement.

Turmel, M.-S., Speratti, A., Baudron, F., Verhulst, N., Govaerts, B., 2015. Crop residue management and soil health: A systems analysis. Agric. Syst. 134, 6–16.

Twomlow, S.J., Urolov, J.C., Jenrich, M., Oldrieve, B., 2008. Lessons from the field– Zimbabwe's conservation agriculture task force. J. SAT Agric. Res. 6, 1–11.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 is the methodology section of this thesis. This study aimed at answering the following research questions:

- Does different residue retention strategies improve soil aggregation that increases water infiltration?
- What effect does residue retention have on soil macro fauna activities in maize production systems?
- Does retention of crop residues in maize production systems influence N flows which have a direct contribution to crop chlorophyll content?
- Do different residues retention strategies improve soil fertility build up, water infiltration and moisture retention that enhance maize productivity under CA in Zimbabwe?

The research was carried out as a field experiment and the student was directly involved in data collection with the help of CIMMYT hired labour. Some advanced technological instruments were used in collecting and recording data such as the SPAD-502, Minolta, Tokyo, Japan for chlorophyll measurement and grain moisture meter a mini GAC moisture tester (DICKEY-john Corp.).

3.2 Description of study sites

The study was conducted at two on-station sites namely University of Zimbabwe farm (UZ) located (17°80´ S, 31°51E´and 1503 meters above sea level (m.a.s.l)) and at Domboshava Training Centre (DTC, 17°36´ S, 31°26 E and 1560 m.a.s.l) for 2017-2018 season, 2018-2019 season. Both sites are in natural region IIb of Zimbabwe and receive an average of 700 -1000 mm rainfall per season in a unimodal pattern (Mugandani et al., 2012). Rainfall starts in November and ends in April and mid-summer temperatures range from 15.5° C to 25.0° C. Both sites are predominated by intensive and semi-intensive farming (Mugandani et al., 2012).

The UZ farm is located at 12.5 km peg along Mazowe-Harare road and is characterised by clay soils classified as *Chromic Luvisols* under FAO (40% clay) that have relatively high soil organic matter content (Jones et al., 2013). Domboshava Training Centre is a Centre for agricultural training and research. It is located 27 km North-East of Harare in Goromonzi District, Mashonaland East Province. Soils at DTC are sandy (5% clay); moderately deep (100cm) and classified as *Luvisols and Arenosols* (FAO classification system) (Jones et al., 2013). Soils at DTC are derived from granitic rocks.

3.3 Experimental design and treatment description

The experiment was set as a randomised complete block design (RCBD) with two main treatments and 4 sub treatments replicated six times.

Main treatments:

1) No till
2) Till

Sub treatments

a) No residues
b) 3t/ha maize residues
c) 3t/ha pigeon pea residues
d) 6t/ha maize residues

Each plot measured 5m ×5m. A crop residue of the required type and quantity was applied in each cropping season. Crop residues were either spread on the soil surface or incorporated into the soil depending on the main treatment. Incorporation of previous crop residues was done by digging trenches (20cm deep) and residues were placed in the trenches. Ridges approximately 30cm high were constructed on top of the trenches burying the residues. This mimics the cropping system in Malawi where ridge and furrow systems are annually made and crop residues are incorporated into the ridges (Ngwira et al., 2013; Thierfelder et al., 2013a, 2013b).

The commercial maize, medium maturity variety (PAN53) was sown under rain fed conditions at 90cm × 25cm spacing with 1 plant per planting station aiming at a target plant population of 44,444 plants ha^{-1}. Basal fertiliser applied was compound D at 100 kg ha^{-1} (7kg N, 14 kg P_2O_5 ha^{-1} and 7 kg K_20 ha^{-1}) and top dressing of ammonium nitrate was done at 100kg ha^{-1} (34.5 kg N ha^{-1}). Pest control was done using Eco-Terex granules dropped in the leaf funnel when necessary applied at a rate of 4 kg ha^{-1} and the active ingredients are

Deltamethrin (0.1%) and Pirimiphos methyl (0.4%). All plots received a herbicide application with glyphosate (N-phosphonomethyl glycine, 41% active ingredient) at a rate of 3l ha^{-1} for an initial weed control application at sowing. Two hand hoe weedings were done when weeds reached 10 cm in height or circumference.

3.4 Data collection procedure

Water infiltration

Water infiltration was measured using the time to pond method described by Verhulst *et al.* (2011) and done by Ngwira *et al.* (2012) for Malawi. Measurements were taken at two positions per plot. A metal wire ring of 50 cm diameter was placed on the soil surface and water irrigated in the middle of the ring using a rose nozzle. A timer was set and once the water reaches the ring, the time was stopped and recorded. Amount of water added to fill the container was measured. The time taken for water to flow out of the metal ring was the time-to-pond. The results were reported in mm hr^{-1}.

Soil macro fauna densities

To determine the number of soil organisms under each treatment, soil monoliths measuring 25 cm × 25 cm × 30 cm deep were extracted from which three layers (0-10 cm, 10-20 cm and 20-30 cm) were handled separately. The measurements were taken approximately 60 days after planting when there was high soil moisture content. Samples from the monoliths were hand-sorted for macro fauna, (beetle larvae, earthworms and termites) assessment. Number of organisms found was recorded and the soil macro-organism were retained to the soil.

Chlorophyll content

A portable chlorophyll meter (SPAD-502, Minolta, Tokyo, Japan) was used on five leaves along the two central rows in each plot prior to flowering and during grain filling up to when the crop dries out. The spad meter took chlorophyll content of the five plants and averaged the readings per plot. Chlorophyll measurements on maize plants involved placement of the meter on the fifth leaf from the bottom, midway between the midrib and the leaf margin and about 20 cm from the stalk (Markwell et al., 1995).

Maize and biomass yield

Maize grain weights were recorded from four central rows by 5 m (net plot) in each plot. The maize cobs and stalks were weighed in the field and a subsample taken for dry matter determination. Subsamples consisted of 10 cobs per plot which were randomly selected weighed, air-dried, shelled, and the grain moisture content determined using a mini GAC moisture tester (DICKEY-john Corp.) and then reweighed (at 0.1 g precision). Maize grain yield was calculated and then converted to kg per hectare at 12.5% moisture content.

3.5 Data analysis procedure

Generalised linear model of R studio was used to test the interactive effects of fixed factors (cropping system, different crop residues quantity, experimental site and season) on grain and biomass yield, water infiltration, chlorophyll and soil macro fauna densities. Replication of treatments in all sites was the random factor. Where treatment means were significantly different, separation was done using the least significant differences (LSD) test at 0.05 probability level.

3.6 Ethical considerations

To carry out this study, the student used CIMMYT confidential information solely and did not disclose it to any party outside CIMMYT without the express prior written consent of the CIMMYT IP/Legal team. To avoid plagiarism the student acknowledges the authors. Highest level of objectivity in discussions and analysis through ought the research was maintained.

3.7 Summary

The goal of this chapter 3 was to outline the research method used to answer the research questions. A discussion of the procedure, data collection and analysis outlined the specifics of how the study was conducted. The next Chapters 4 and 5 to follow will demonstrate if the methodology in this chapter was followed throughout the research.

3.8 References

Jones, A., Breuning-Madsen, H., Brossard, A., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R., 2013. Soil atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Markwell, J., Osterman, J.C., Mitchell, J.L., 1995. Calibration of the Minolta SPAD-502 leaf chlorophyll meter. Photosynth. Res. 46, 467–472.

Mugandani, R., Wuta, M., Makarau, A., Chipindu, B., 2012. Re-classification of agro-ecological regions of Zimbabwe in conformity with climate variability and change. Afr. Crop Sci. J. 20, 361–369.

Ngwira, A.R., Thierfelder, C., Lambert, D.M., 2013. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renew. Agric. Food Syst. 28, 350–363.

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S., Rusinamhodzi, L., 2013a. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crops Res. 142, 47–57.

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S., Rusinamhodzi, L., 2013b. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crops Res. 142, 47–57.

Verhulst, N., Kienle, F., Sayre, K.D., Deckers, J., Raes, D., Limon-Ortega, A., Tijerina-Chavez, L., Govaerts, B., 2011. Soil quality as affected by tillage-residue management in a wheat-maize irrigated bed planting system. Plant Soil 340, 453–466.

CHAPTER 4

An evaluation on the effects of different residue retention strategies on water infiltration and soil macro-fauna under conservation agriculture systems in Zimbabwe**.**

Abstract

The livelihoods of more than 2 billion people depend solely on agricultural activities. Vast increase in population has resulted in pressure on resources leading to massive land degradation mostly on the cropping lands. Poor farming methods practiced by smallholder farmers increases soil erosion and also reduce the effects of soil fauna which results in poor biomass and grain yields. A study to evaluate the effects of different residue retention strategies on water infiltration and soil macro-fauna in Zimbabwe was carried out at a sandy site at Domboshava Training Centre (DTC) and a clayey site the University of Zimbabwe (UZ) farm. The experiment was laid as a randomised completely block design during 2017/18 and 2019/2019 cropping seasons. The results showed crop residue retention strategies, sites and seasons had an influence on water infiltration. Maize crop residues promoted higher infiltration than pigeon pea crop residues. Soil macrofauna densities were significantly (p <0.05) affected by crop residue retention strategies. Thus, retaining crop residues in no-till systems overcomes moisture scarcity challenge commonly faced by smallholder farmers in Zimbabwe.

Keywords: Crop residues management, tillage system, Infiltration and Soil macro-fauna

4.1 Introduction

Smallholder farmers grow most of the food that is required to feed the African population which is expected to rise by 2.4% per annum, projected from 2015 and 2050 (Nyasimi et al., 2014). Most smallholder farmers in Zimbabwe depend on natural rainfall for crop production. The rainfall pattern is currently often unpredictable and involves long dry spells during the cropping seasons (Verschuren et al., 2000). The effects of long dry spells are further exacerbated by conventional ploughing which predisposes soil to erosion, excessive runoff and evaporation (Reganold et al., 1987; Evans, 2013). Thus, agricultural practices that reduce rainfall runoff and improve infiltration are crucial in the smallholder cropping systems.

Soil water infiltration helps the soils to temporarily store water for use by crops and soil biota, thus improving crop productivity and soil fertility. Infiltration rate is affected by soil texture, a major inherent factor that cannot be changed and by soil structure, (Govaerts, 2007). Soils with course particle sizes such as sandy soils allow quick more rapid water movement through the soil profile than those with small particle size such as clayey soils. However, soil water infiltration can be managed by good agricultural practices that promote development of soil structure and porosity through groundcover and minimize compaction (Thierfelder and Wall, 2009). Groundcover can be improved by using different mulching materials, such as crop residues, grasses or tree leaves, as well as crops with high ground cover in smallholder farms. Covering the ground reduces direct raindrop impact that displace soil particles which fill up and block surface pores, thus reducing soil erosion (Ngwira et al,. 2012). On the other hand, the mulching materials reduce rainfall runoff by reducing runoff velocity and promote more infiltration of water (Thierfelder and Wall, 2009; Herrmann et al., 2014).

The presence of mulch as a groundcover promotes organic matter build-up and reduces soil temperature fluctuations which favour soil macro-organisms. The mulching material can also act as feed for the organisms such as termites and earthworms which also contribute to rainfall infiltration (Léonard and Rajot, 2001; Thierfelder et al., 2005; Jouquet et al., 2012). Earthworms burrow in the soil that creates water ways and improve soil aeration thus promoting crop growth (Caro et al., 2014; Marhan et al., 2015). Also, earthworms facilitate retention of nitrogen into the soil through feeding on leaf litter (Yang et al., 2015).

Tillage systems have a direct effect on water infiltration (Lipiec et al., 2006). Minimum tillage promote aggregate stability which increases infiltration (Dao, 1993). Conventional tillage system loosens the soil particles resulting in soil erosion which carries nutrients and organic matter thus reducing soil fertility and thereby affecting plant growth. Conventional practices accompanied by removal of crop residues reduces water infiltration rate compared to No tillage practice plus crop residue retention (Liben et al., 2018).

Earthworm densities affect water infiltration in the soil. Earthworms movement in the soil form burrows which play a great role in water movement and its faeces evolve into soil as crumbs, that are more or less stable, to create a typical granular soil structure. Together, crumbs and burrows, increase water infiltration and soil stability and, thus, reduce water runoff and soil erosion (Bouché and Al-Addan, 1997). Hence there is less water stored in the soil for plant growth, and plant production decreases, resulting in less organic matter in the soil and weakened soil structure that can further decrease the infiltration rate.

Maintaining permanent soil cover, a principle under Conservation agriculture system has proved to increase water infiltration (Brouder and Gomez-Macpherson, 2014; TerAvest et al., 2015). Mulching the soil surface with a layer of plant residue is an effective method of conserving water and soil because it reduces surface runoff, increases infiltration of water into the soil and retard soil erosion (Adekalu et al., 2007; Baumhardt et al., 2012; Dao, 1993). Conservation Agriculture has the potential to maintain high infiltration rates and conserve soil moisture thus reducing crop failure due to midseason dry spells (Thierfelder et al., 2017; Thierfelder and Wall, 2009).

Methods of measuring infiltration

There are different methods that are used to measure infiltration in the soil. The method to use needs to be determined for each study depending on research objectives, available resources and production system. The different methods of measuring infiltration follow:

Double ring infiltrometer

When measuring infiltration using double ring infiltrometer, two rings are hammered 10cm into the soil. An inner ring is driven into the ground and a second bigger ring around that to help control the flow of water through the first ring. ASTM standard method specifies inner and outer rings of 30 and 60cm diameters respectively (ASTM 2003). Bouwer (1986) describes that when using the double ring infiltrometer, two operational techniques are used with the double-ring infiltrometer for measuring the flow of water into the ground. In the constant head test, the water level in the inner ring is maintained at a fixed level and the volume of water used to maintain this level is measured. In the falling head test, the time that the water level takes to decrease in the inner ring is measured. In both constant and falling head tests, the water level in the outer ring is maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring. Gregory (2005) supports that to achieve good measuring results it is very important to take into account several factors that may influence the measurements: the surface vegetation, the extent to which the soil has been compacted, the soil moisture content and the soil layers (strata). The best measuring results are obtained at field capacity of the soil. It is preferable that the rings are covered with plastic bags during the measurements to prevent evaporation. It can be argued that measuring infiltration using double ring infiltrometer is a time consuming and invasive measurement. Furthermore, taking measurements with a double ring infiltrometer will always saturate the soil.

Single ring infiltrometer

This method involves driving a ring into the soil and supplying water in the ring at constant head condition (amount of water in the ring is always held constant) the operator records how much water goes into the soil for a given time period Bouwer (1986). Single ring infiltrometer approach is faster and does not disrupt the field to the same extent as the double ring infiltrometer, but it is less accurate as it does not compensate for lateral flow. An advantage of using small ring infiltration is that it can be used to compare between plots multiple times during the growing season. Small ring infiltration measurements can be achieved with a variable amount of water. Using a small amount of water will give an indication of what happens during rainfall events, while using larger amounts will yield a value more similar to the basic infiltration rate. Bouwer (1986) found that infiltration rates based on cylinder infiltrometer measures are fraught with errors and uncertainties. Measurement errors can occur due to soil disturbance by the insertion of the cylinder into the soil. In soils with a surface crust or other restricting layers at or near the surface, infiltrometer can disrupt such restricting layers resulting in drastic increases in infiltration rates. Also, clays and other fine particles, temporarily brought into suspension in the water inside the cylinder, can settle out on the soil during the measurement, creating a restricting layer on the surface.

The time-to-pond methodology

Was proposed by Govaerts et al., (2006) to overcome some errors of other methods and provide a fast, reliable, and simple (thus, potentially useful for on-farm research) measure of direct surface infiltration. In this methodology, a metal wire ring of 50 cm diameter is placed over the soil surface to avoid soil structure disruption and water is irrigated in the middle of the ring using a rose nozzle. A timer is set and once the water reaches the ring, the time is stopped and recorded. Amount of water added to fill the container is measured. The time taken for water to flow out of the metal ring is the time-to-pond. The results will be recorded in mm hr^{-1}. This methodology provides an indirect measure of runoff as water that flow out of the area is not impeded by the wire. Time-to-pond provides a measure of infiltration versus runoff in which both aspects, physical soil quality and management, are accounted for. Thus, measurements not only provide a basis for infiltration comparisons between soils but also information on management practices related to reduce runoff incidence. Time-to-pond values can only be used to make comparisons between plots in a single trial. As it is a fast and easy measurement it can also be used in the field to show farmers the difference in infiltration between fields.

4.2 Materials and Methods

4.2.1 Site description

Field experiment under rain fed conditions was established at two on station sites namely University of Zimbabwe farm (UZ) and at Domboshava Training Centre (DTC).The description of the sites is explained in detail in chapter 3.

4.2.2 Experimental design and treatment description

The experiment was set as a randomised complete block design (RCBD) with two main treatments; no-till and conventional tillage and four sub treatments; no crop residue retention, 3 t ha^{-1} maize crop residues, 3 t ha^{-1} pigeon pea crop residues and 6 t ha^{-1} maize crop residues) that were replicated six times at each site.

Land preparation was done in October for 2017-2018 and 2018-2019 seasons. Each plot was 5m wide and 5m long. Crop residues of the required type and quantity were applied in each cropping season. Crop residues were either spread on the soil surface or incorporated into the soil depending on the main treatment. Incorporation of previous crop residues was done by digging trenches (20cm deep) and residues were placed in the trenches. Ridges approximately 30cm high were constructed on top of the trenches burying the residues. This mimics the cropping system in Malawi where ridge and furrow systems are annually made and crop residues are incorporated into the ridges (Thierfelder et al., 2013)

The commercial maize, medium maturity variety PAN53 was sown under rain fed conditions at 90cm × 25cm spacing with 1 plant per planting station aiming at a target plant population of 44,444 plants ha^{-1}. Basal fertiliser was applied using compound D at 100 kg ha^{-1} (7kg N, 14kg P_2O_5 ha^{-1} and 7kg K_20 ha^{-1}) and top dressing using ammonium nitrate applied at 100kg ha^{-1} (34.5 kg N ha^{-1}). Pests control was done using Eco-Terex granules dropped in the leaf funnel when necessary applied at a rate of 4kg ha^{-1} and the active ingredients are

Deltamethrin (0.1%) and Pirimiphos methyl (0.4%). All plots received a herbicide application with glyphosate (N-(phosphonomethyl) glycine, 41% active ingredient) at a rate of 3l ha^{-1} for an initial weed control application at sowing. Two hand hoe weeding were done when weeds reached 10cm in height or circumference.

4.2.3 Data collection and analysis

Water infiltration was measured using the time to pond method described by Verhulst *et al.,* (2011) and done by Ngwira et al,. (2012) for Malawi. Measurements were taken at two positions per plot. A metal wire ring of 50 cm diameter was placed on the soil surface and water irrigated in the middle of the ring using a rose nozzle. A timer was set and once the water reaches the ring, the time was stopped and recorded. Amount of water added to fill the container was measured. The time taken for water to flow out of the metal ring was the time-to-pond. The results were reported in mm h^{-1}.

To determine the number of soil organisms under each treatment, soil monoliths measuring 25cm ×25cm ×30 cm deep were extracted from which three layers (0-10 cm, 10-20 cm and 20-30 cm) and were handled separately. The measurements were taken approximately 60 days after planting when there was high soil moisture content .Samples from the monoliths were hand-sorted for macro fauna, (beetle larvae, earthworms and termites) assessment (Nhamo 2009). Number of organisms found was recorded and the soil macro-organism were retained to the soil.

Generalised linear model of R studio was used to test the interactive effects of fixed factors (cropping system, different crop residues quantity, experimental site and season) on water infiltration. Replication of treatments in all sites was the random factor. Where treatment means were significantly different, separation was done using the least significant differences (LSD) test at 0.05 probability level.

4.3 Results

Seasonal rainfall

More rainfall was received during the 2017 – 2018 cropping season at both sites and the lowest rainfall was recorded at UZ during 2018 – 2019 season (Figure 4.1).

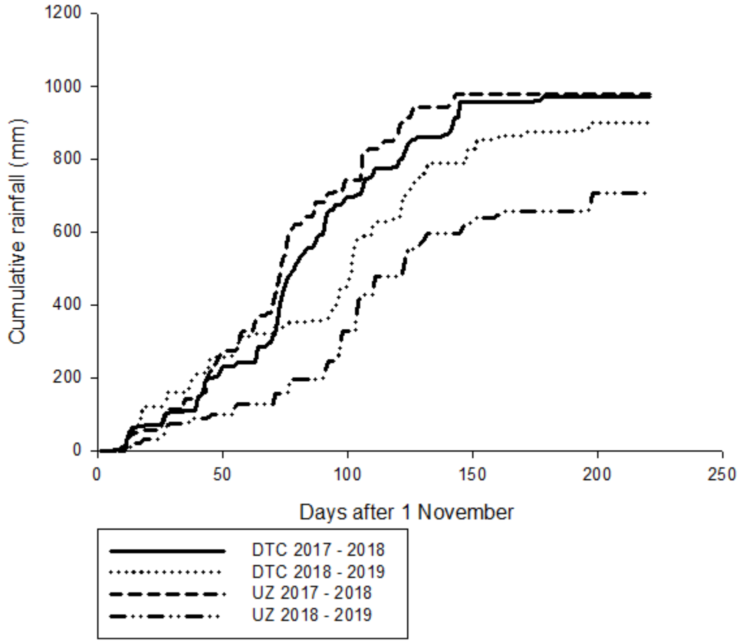

Figure 4.1: Cumulative rainfall at Domboshava Training Centre and University of Zimbabwe farm during 2017 – 2019 cropping seasons

Infiltration

The results show that main treatments, sub-treatments, year, sites and their interactions had a significant effect on water infiltration; except Sub-treatment × year, Sub-treatment × year ×site and Treatment × Sub-treatment × year × site interactions (Table 4.1).

Table 4.1: Effect of crop residue retention strategies on water infiltration at Domboshava Training Centre and University of Zimbabwe farm

	DF	F-value	Pr (>F)
Main treatments	1	16.92	4.898e-05 ***
Sub-treatment	3	5.06	0.001856 **
Year	1	8.41	0.003716 **
Site	1	30.82	7.854e-08 ***
Treatment × sub-treatment	3	5.28	0.001375 **
Treatment × year	1	7.41	0.006402 **
Sub-treatment × year	3	2.49	0.056033
Treatment × site	1	11.11	0.006402 **
Sub-treatment × site	3	3.32	0.018692 *
Year × site	1	4.60	0.030818 *
Treatment × Sub-treatment × year	3	3.27	0.020038 *
Treatment × Sub-treatment ×site	3	3.74	0.010742 *
Sub-treatment × year ×site	3	1.84	0.131811
Treatment × Sub-treatment× year × site	3	2.55	0.052061

Significance levels:'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

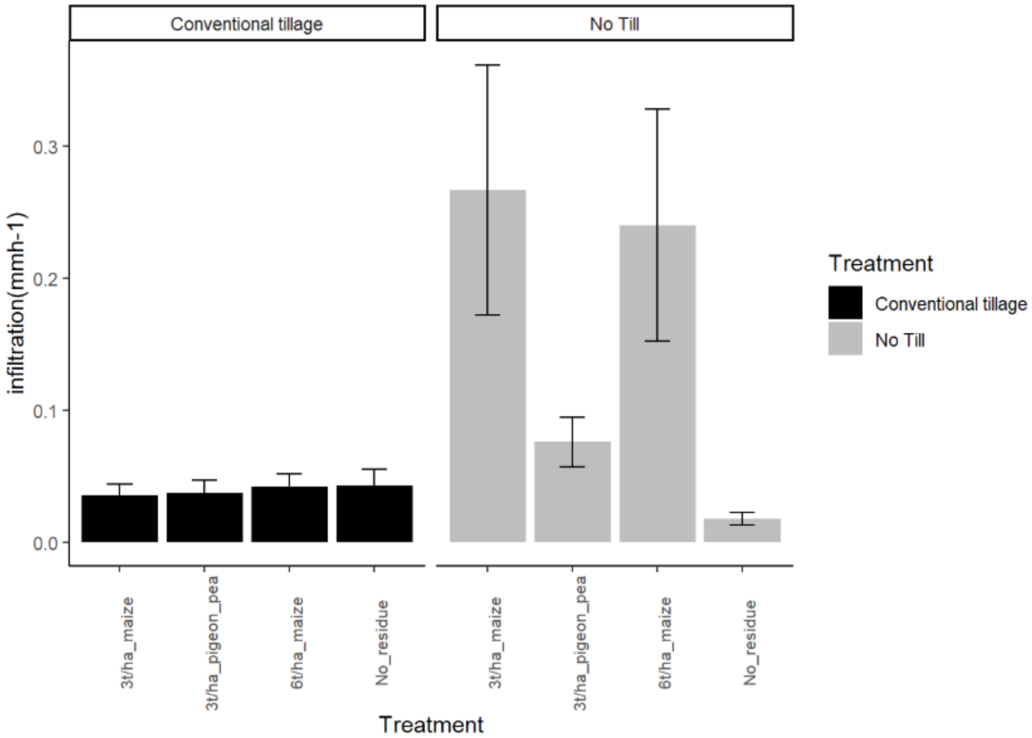

Figure 4.2: Effect of tillage systems and crop retention on water infiltration.

Results show that there was significantly higher infiltration in no-till treatments with crop residues than conventional tillage (Figure 4.2). There was higher infiltration in treatments with maize crop residues than pigeonpea crop residues under no-till (Figure 4.2).

Overall infiltration rate at UZ was higher (0.16 mm h^{-1}) than at DTC (0.02 mm h^{-1}) for both cropping seasons (Table 4.2).

Table 4.2: Infiltration results in different tillage and residue retention strategy at DTC and UZ for both cropping seasons

Site	Year	Main treatments	Sub-treatments	Infiltration rate	Group
DTC	2018	Conventional tillage	3t/ha maize	0.013	a
	2018	Conventional tillage	3t/ha pigeon pea	0.012	a
	2018	Conventional tillage	6t/ha maize	0.004	a
	2018	Conventional tillage	No residue	0.005	a
	2018	No-till	3t/ha maize	0.019	a
	2018	No-till	3t/ha pigeon pea	0.005	a
	2018	No-till	6t/ha maize	0.020	a
	2018	No-till	No residue	0.003	a
	2019	Conventional tillage	3t/ha maize	0.010	a
	2019	Conventional tillage	3t/ha pigeon pea	0.012	a
	2019	Conventional tillage	6t/ha maize	0.015	a
	2019	Conventional tillage	No residue	0.007	a
	2019	No-till	3t/ha maize	0.057	a
	2019	No-till	3t/ha pigeon pea	0.033	a

	2019	No-till	6t/ha maize	0.105	a
	2019	No-till	No residues	0.005	a
UZ	2018	Conventional tillage	No residues	0.047	a
	2018	Conventional tillage	3t/ha maize	0.075	a
	2018	Conventional tillage	3t/ha pigeon pea	0.067	a
	2018	Conventional tillage	6t/ha maize	0.074	a
	2018	No-till	3t/ha maize	0.185	a
	2018	No-till	3t/ha pigeon pea	0.145	a
	2018	No-till	6t/ha maize	0.176	a
	2018	No-till	No residues	0.045	a
	2019	Conventional tillage	3t/ha maize	0.046	a
	2019	Conventional tillage	3t/ha pigeon pea	0.058	a
	2019	Conventional tillage	6t/ha maize	0.076	a
	2019	Conventional tillage	No residues	0.112	a
	2019	No-till	3t/ha maize	0.806	b
	2019	No-till	3t/ha pigeon pea	0.121	a
	2019	No-till	6t/ha maize	0.660	b
	2019	No-till	No residues	0.018	a

Soil macrofauna

Effect of tillage systems and crop residue retention strategies on total soil macro-fauna density

The results show that only sub-treatments had a significant effect on the total soil macrofauna-density. All other factors tested and their interactions had no significant effect on total soil macrofauna density.

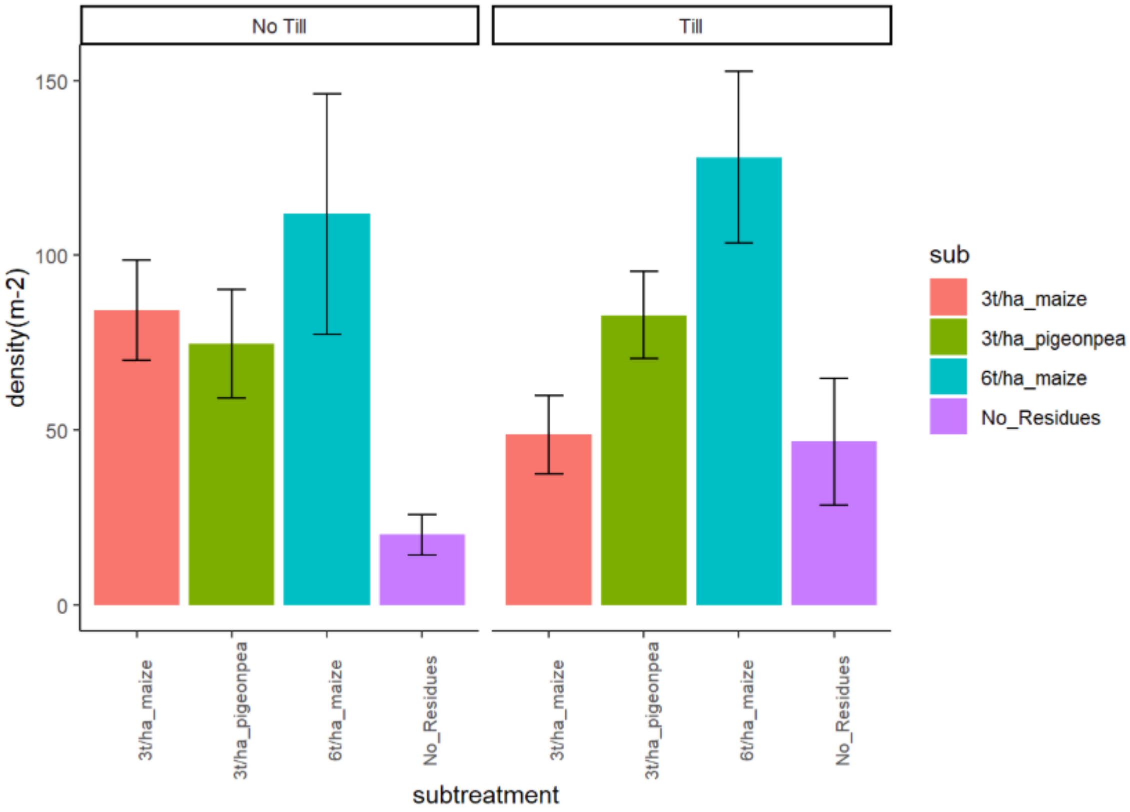

Figure 4.3: Effect of crop residue retention strategies on total soil macrofauna at Domboshava Training Centre and University of Zimbabwe farm during 2017 – 2019 cropping seasons

Different crop residue retention strategies had a significant effect on macrofauna densities. High macrofauna densities were recorded at 6t ha^{-1} maize residues in both cropping systems (Figure 4.3). In both systems increase in crop residues quantities also resulted in increased macrofauna densities. Highest densities was recorded at 6t h^{-1} maize crop residues in both systems and lower in no residues (Figure 4.3).

In both seasons and at all sites, earthworm density was significantly affected by cropping systems (Table 4.3). Earthworm density was high in conventional tillage and lower in no till system. However, increase in crop residue quantity resulted in an increase in earthworms in both systems. In both systems, low earthworms were observed the 2017/18 cropping season and increased in 2018/2019 season.

Table 4.3: Macrofauna densities at Domboshava Training Centre (DTC) and University of Zimbabwe farm (UZ) during 2017 – 2019 cropping seasons

Sites	Seasons	Macro-organisms	No residues	3t/ha pigeon pea residues	3t/ha maize residues	6t/ha maize residues	No residues	3t/ha pigeon pea residues	3t/ha maize residues	6t/ha maize residues	LSD	*P-value*
			No-tillage				Conventional ploughing					
DTC	2017/18	beetles	3.56^{a}	0.89^{a}	5.33^{a}	0.89^{a}	0.89^{a}	1.78^{a}	3.56a	0.89^{a}	*NS*	*NS*
		earthworms	0.00^{b}	1.78^{b}	0.89^{b}	5.33^{ab}	0.89^{b}	0.00^{b}	4.44^{ab}	10.67^{a}	*NS*	*NS*
		millipedes	0.00^{b}	0.00^{b}	0.89^{b}	0.89^{b}	0.89^{b}	0.00^{b}	0.00^{b}	3.56^{a}	*NS*	*NS*
		termites	29.33^{a}	99.56^{a}	91.56^{a}	112.00^{a}	104.00^{a}	82.67^{a}	10.67^{a}	88.00^{a}	*NS*	*NS*
	2018/19	beetles	5.33^{ab}	8.00^{ab}	5.33^{ab}	3.56^{ab}	0.00^{b}	6.22^{ab}	4.44^{ab}	12.44^{a}	*NS*	*NS*
		earthworms	0.00^{b}	1.78^{b}	0.89^{b}	5.33^{ab}	0.89^{b}	0.00^{b}	4.44^{ab}	10.67^{a}	*NS*	*NS*
		millipedes	0.00^{a}	0.00^{a}	0.00^{a}	2.67^{a}	1.78^{a}	0.00^{a}	0.00^{a}	0.00^{a}	*NS*	*NS*
		termites	21.33^{a}	98.67^{a}	108.44^{a}	120.89^{a}	47.11^{a}	80.89^{a}	8.89^{a}	94.22^{a}	*NS*	*NS*
UZ	2017/18	beetles	4.44^{a}	8.89^{a}	8.00^{a}	6.22^{a}	0.89^{a}	8.89^{a}	6.22^{a}	10.67^{a}	*NS*	*NS*
		earthworms	14.22^{d}	52.44^{bcd}	62.22^{bcd}	91.56^{abc}	20.44^{cd}	94.22^{ab}	88.89^{abc}	147.56^{a}	*36.61*	*0.01*
		millipedes	0.00^{b}	2.67^{ab}	1.78^{ab}	8.00^{a}	0.00^{b}	6.22^{ab}	4.44^{ab}	0.89^{b}	*NS*	*NS*
		termites	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	2.67^{a}	*NS*	*NS*
	2018/19	beetles	5.34^{b}	8.00^{ab}	5.33^{ab}	3.56^{ab}	0.00^{b}	6.22^{ab}	4.44^{ab}	12.44^{a}	*NS*	*NS*
		earthworms	0.89^{c}	22.22c	40.89^{bc}	80.89^{ab}	6.22^{c}	44.44^{bc}	49.78^{bc}	111.11^{a}	*28.37*	*0.002*
		millipedes	0.00^{b}	1.78^{b}	2.67^{b}	8.89^{a}	0.00^{b}	5.33^{ab}	3.56^{ab}	0.89^{b}	*NS*	*NS*
		termites	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	2.67^{a}	*NS*	*NS*

Numbers with different letters are significantly different from each other. NS means not significant.

4.4 Discussion

Results show that several factors including tillage practices and crop residue retention strategy has an effect on water infiltration. Maintaining crop residues on the soil surface improves infiltration. This is because the crop residues increases soil cover which reduces the velocity of runoff during rainfall invents thus encouraging more infiltration. Also addition of crop residues on the soil surface increases the roughness on the soil which also promotes infiltration and ponding of rain water (Jordán et al., 2010). Furthermore, addition of crop residues on the surface reduces the energy of the raindrops which otherwise loosen the soil and increase soil erosion (Alberts and Neibling, 1994). Govaerts (2007) supports that residues left in the field can intercept water and allow water to infiltrate slowly (referred to as 'horizontal' mulching effect). Removing crop residues, which is common in Zimbabwe smallholder farms, leaves the soil exposed to the raindrop impact making them vulnerable to runoff. Exposure of the soils to rain impact results in soil crusting which reduces water infiltration (BU et al., 2014). Crop biomass increases structural stability for increased infiltration (Reicosky and Wilts, 2005). Infiltration rate increased with increase in quantities of crop residues applied. This may be related to high groundcover provided by the crop residues. Maize crop residues resulted in higher infiltration than pigeon pea residues in no-tillage systems. This may be due to the fact that pigeon pea leaves decomposed faster leaving mostly stems hence lower soil cover, unlike maize residues.

Contrary to available literature, DTC a site with sandy soils (that have high soil particle size) had lower infiltration than UZ that is characterised by clay soils. This maybe a result of previous differences in management practices of the fields before the trials were established. This challenge could be addressed by continuing the study for several cropping systems so that the treatments buffer out the previous management effects.

Crop residue retention strategies had a significant effect on total macro-fauna density. Nhamo, (2007) reported that application of surface mulches, crop or grass residues, that contain cellulose and crude protein attracted more macro-organisms and this increased their activities on plots with minimal soil disturbance. The low rainfall received in all seasons did not favour the activities for soil macroorganisms. Lavell and Spain (2001) suggests that soil water status is a major limitation to earthworm activities and distribution, since they cannot withstand prolonged dry periods. High quantities of crop residues increase earthworm densities which promote soil burrowing thus increase water infiltration. No till combined with crop residue retention on the soil surface, can improve water infiltration (Shaver et al., 2002), and greatly reduce erosion and enhance water use efficiency (Johnston et al., 2002) compared to conventional tillage. Addition of crop residues also increases soil macrofauna activities which has an effect on maize productivity in smallholder farms.

4.5 Conclusions

Based on the findings from this study, the following conclusions were made:

Water infiltration was influenced by tillage systems, crop residue retention strategies, sites and their interactions. Addition of crop residues on the soil surface in no-till systems improves infiltration by reducing runoff and raindrop energy. High water infiltration reduces the moisture scarcity problems that are commonly faced by farmers.

Retention of crop residues either at the soil surface or incorporated in the soil has an influence on total soil macrofauna activity. Maize crop residues increase the abundance of soil macro-fauna. Pigeon pea crop residue was mostly stems during most of the cropping season hence, less groundcover and infiltration.

Thus, it can be concluded that use of crop residues in no-till systems has potential to overcome moisture scarcity problems and improve soil biota activity which increases the overall productivity in smallholder farms in Zimbabwe.

4.6 References

Adekalu, K.O., Olorunfemi, I.A., Osunbitan, J.A., 2007. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresource Technology 98, 912–917. https://doi.org/10.1016/j.biortech.2006.02.044

Alberts, E., E., Neibling, H., W., 1994. Influence of crop residues on water erosion. Managing agricultural residues. USA.

Baumhardt, R., Johnson, G., Schwartz, R., 2012. Residue and long-term tillage and crop rotation effects on simulated rain infiltration and sediment transport. Soil Science Society of America Journal 76, 1370–1378.

Bouché, M.B., Al-Addan, F., 1997. Earthworms, water infiltration and soil stability: some new assessments. Soil biology and biochemistry 29, 441–452.

Brouder, S.M., Gomez-Macpherson, H., 2014. The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. Agriculture, Ecosystems & Environment 187, 11–32. https://doi.org/10.1016/j.agee.2013.08.010

BU, C., WU, S., YANG, K., 2014. Effects of physical soil crusts on infiltration and splash erosion in three typical Chinese soils. International Journal of Sediment Research 29, 491–501. https://doi.org/10.1016/S1001-6279(14)60062-7

Dao, T.H., 1993. Tillage and winter wheat residue management effects on water infiltration and storage. Soil Science Society of America Journal 57, 1586–1595.

Jordán, A., Zavala, L.M., Gil, J., 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. CATENA 81, 77–85. https://doi.org/10.1016/j.catena.2010.01.007

Liben, F.M., Tadesse, B., Tola, Y.T., Wortmann, C.S., Kim, H.K., Mupangwa, W., 2018. Conservation Agriculture Effects on Crop Productivity and Soil Properties in Ethiopia. Agronomy Journal 110, 758–767. https://doi.org/10.2134/agronj2017.07.0384

Lipiec, J., Kuś, J., Słowińska-Jurkiewicz, A., Nosalewicz, A., 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage Research 89, 210–220. https://doi.org/10.1016/j.still.2005.07.012

Nhamo, N., 2007. The contribution of different fauna communities to improved soil health: a case of Zimbabwean soils under conservation agriculture. ZEF.

Reicosky, D.C., Wilts, A.R., 2005. CROP-RESIDUE MANAGEMENT, in: Hillel, D. (Ed.), Encyclopedia of Soils in the Environment. Elsevier, Oxford, pp. 334–338. https://doi.org/10.1016/B0-12-348530-4/00254-X

TerAvest, D., Carpenter-Boggs, L., Thierfelder, C., Reganold, J.P., 2015. Crop production and soil water management in conservation agriculture, no-till, and conventional tillage systems in Malawi. Agriculture, Ecosystems & Environment 212, 285–296. https://doi.org/10.1016/j.agee.2015.07.011

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S., Rusinamhodzi, L., 2013. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crops Research 142, 47–57.

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T.S., Lamanna, C., Eyre, J.X., 2017. How climate-smart is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. Food Security 9, 537–560. https://doi.org/10.1007/s12571-017-0665-3

Thierfelder, C., Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105, 217–227. https://doi.org/10.1016/j.still.2009.07.007

Verhulst, N., Kienle, F., Sayre, K.D., Deckers, J., Raes, D., Limon-Ortega, A., Tijerina-Chavez, L., Govaerts, B., 2011. Soil quality as affected by tillage-residue management in a wheat-maize irrigated bed planting system. Plant and Soil 340, 453–466.

CHAPTER 5

The effect of different residue retention strategies on leaf chlorophyll content ,maize grain and stover yield under no till systems in Zimbabwe.

Abstract

To feed the growing population in Zimbabwe smallholder farmers, who produce most of the food to feed this population, need to improve their cropping systems. Conservation agriculture has been practiced and shown to offer more benefits to address food insecurity. However, challenges with management of crop residues are still high. A study to evaluate the effects of different residue retention strategies on maize chlorophyll content and yield was conducted at a sandy site and a clayey site in Zimbabwe. The results showed maize chlorophyll content was significantly affected by soil type, season quality and the tillage systems. The sandy site had lower chlorophyll content than clay site, and conventional tillage treatments had higher chlorophyll than no till treatments. Conventional ploughing had higher grain yields than no till treatment. Although conventional tillage had higher yields than no till, continuous tillage deteriorates the soil quality over time which later results in low crop yields. Thus, no till systems combined with use of crop residues has potential to produce high yields over time than conventional tillage systems.

Keywords: Crop residues management, tillage systems, Infiltration and Soil macro-fauna

5.1 Introduction

Food insecurity in smallholder farming systems in Zimbabwe remains a key challenge to address. The problems with climate change and limited resources often results in low maize yields obtained by farmers, average yields is less than 1 ton ha^{-1} (Baudron et al., 2012). To improve the maize yield in smallholder farming systems in Zimbabwe, conservation agriculture (CA) has been recommended. It involves three key principles namely, diverse crop rotation, minimum soil disturbance and diverse crop rotations or crop interactions. Several researchers have reported the benefits of CA e.g. Mupangwa et al., (2017); O’Dell et al., (2020); Rusinamhodzi et al., (2011). Adoption of CA in Zimbabwe and other countries in sub-Saharan Africa is hindered by several factors which include high competition for residue use (Duncan et al., 2016; Rusinamhodzi et al., 2015).

Although there is high competition for crop residue use in smallholder farming systems, maintenance of permanent soil cover is an important agronomic practice that helps improve productivity (Kodzwa et al., 2020). Crop residue management serve a double function in mitigating global warming and food insecurity by increasing carbon sequestration in agricultural systems and increasing grain yields. The quality of crop residues used has an influence on nutrient availability. Crop residues with high C/N ratio results in N lock-up challenges which reduce crop yields. These challenges can be alleviated with different management practices including incorporating them into the soil and spreading them on the soil surface. Hence, the objective of this study was to investigate how management of different residue types and quantities influence maize yield.

5.2 Materials and Methods

The experimental sites, design and management has been provided in detail in chapter 3.

5.2.1 Data collection and analysis

a) Chlorophyll content

A portable chlorophyll meter (SPAD-502, Minolta, Tokyo, Japan) was used on five fixed leaves along the two central rows in each plot prior to flowering and during grain filling up to when the crops dries out. The spad meter took chlorophyll content of the five plants and averaged the readings per plot. Chlorophyll measurements on maize plants involved placement of the meter on the fifth leaf from the bottom, midway between the midrib and the leaf margin and about 20cm from the stalk (Markwell et al., 1995).

b) Maize biomass yield

Maize grain weights were recorded from four central rows by 5 m (net plot) in each plot. The maize cobs and stalks were weighed in the field and a subsample taken for dry matter determination. Subsamples consisted of 10 cobs per plot which were randomly selected weighed, air-dried, shelled, and the grain moisture content determined using a mini GAC moisture tester (DICKEY-john Corp.) and then reweighed (at 0.1 g precision). Maize grain yield was calculated and then converted to kg per hectare at 12.5% moisture content.

5.3 Data analysis

Generalised linear model of R studio was used to test the interactive effects of fixed factors (cropping system, different crop residues quantity, experimental site and season) on grain and biomass yield. Replication of treatments in all sites was the random factor. Where treatment means were significantly different, separation was done using the least significant differences (LSD) test at 0.05 probability level.

5.4 Results

The results show that tillage systems, site and year had a significant effect on leaf chlorophyll content. Also, the main treatment × site and site × year interactions had a significant effect on the leaf chlorophyll content (Table 5.1).

Domboshava Training Center had lower leaf chlorophyll content than UZ during the 2 cropping seasons (33.7 and 39.8 respectively). Leaf chlorophyll content was also higher during the 2018-2019 cropping season than the 2017-2018 cropping season (Figure 5.1). Overall, at DTC conventional tillage had significantly higher leaf chlorophyll (35.8) than no-till practices (31.7) and at UZ there were no significant differences between the tillage practices.

Table 5.1: The effect of tillage practices and crop residue retention strategies on leaf chlorophyll content at Domboshava Training Centre and University of Zimbabwe Farm in 2017 – 2019 cropping seasons.

	DF	F-value	Pr (>F)
Main treatment	1	8.3628	0.0039193**
Sub-treatment	3	0.9144	0.9002236
Year	1	34.007	0.003716 **
Site	1	88.2428	<2.2e-16***
Main treatment × sub-treatment	3	0.1944	0.9002338
Main treatment × year	1	0.458	0.4987093
Sub-treatment × year	3	0.3767	0.7698291
Main treatment × site	1	11.7839	0.0006239 ***
Sub-treatment × site	3	0.3767	0.7698291
Year × site	1	83.5867	< 2.2e-16 ***
Main treatment × Sub-treatment × year	3	0.608	0.6099099
Main treatment × Sub-treatment × site	3	1.9712	0.1606518
Sub-treatment × year × site	3	0.19	0.9056214
Main treatment × Sub-treatment × year × site	3	0.0749	0.973492

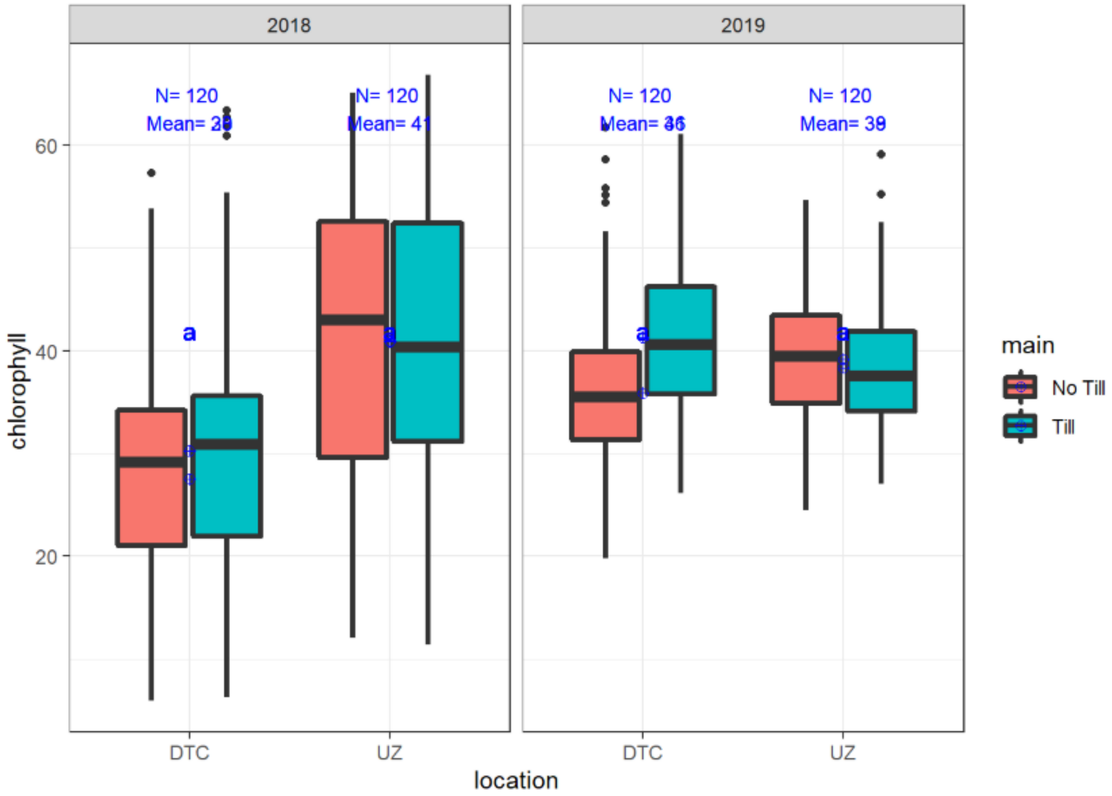

Figure 5.1: Boxplots showing the effect of seasons, tillage systems and site on maize leaf chlorophyll content.

Tillage systems had significant effect on grain yields at DTC (Figure 5.2). Conventional ploughing had higher yield than no-till at DTC in both cropping seasons. Different crop residue quantity and type had no significant effect on grain yield. Grain yield was high at DTC in conventional tillage plots and low in No till plots. At UZ tillage systems had no significant effect on grain yield. There was a general increase in yields from 2017/18 season to 2018/19 season. Biomass yield was significantly affected by tillage systems (Figure 5.3). Biomass yield was high in conventional tillage and low on No till at DTC in both cropping seasons. There was no significant interaction between main and sub treatments on grain and biomass yield at UZ in both cropping seasons.

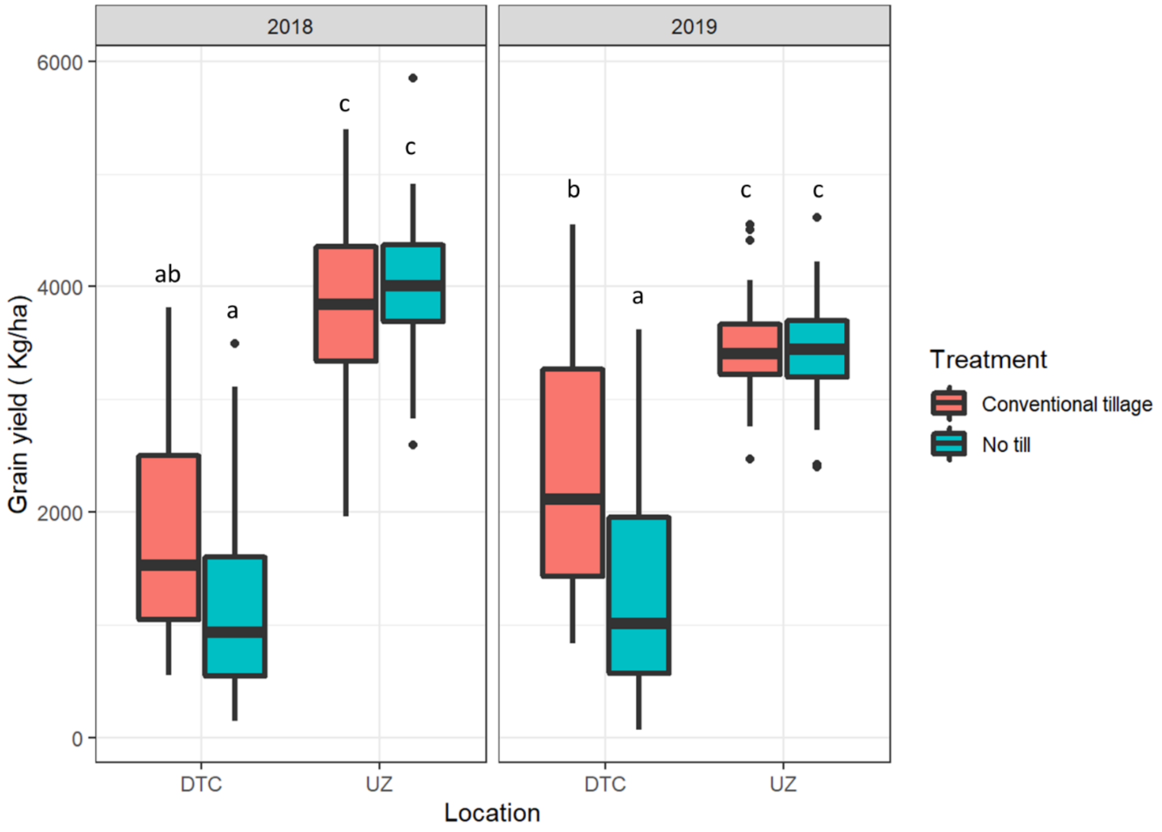

Figure 5.2: Effect of crop residue quality and quantity on maize grain yield in no-tillage and conventional tillage practices at DTC and UZ farm during 2018 and 2019 cropping seasons

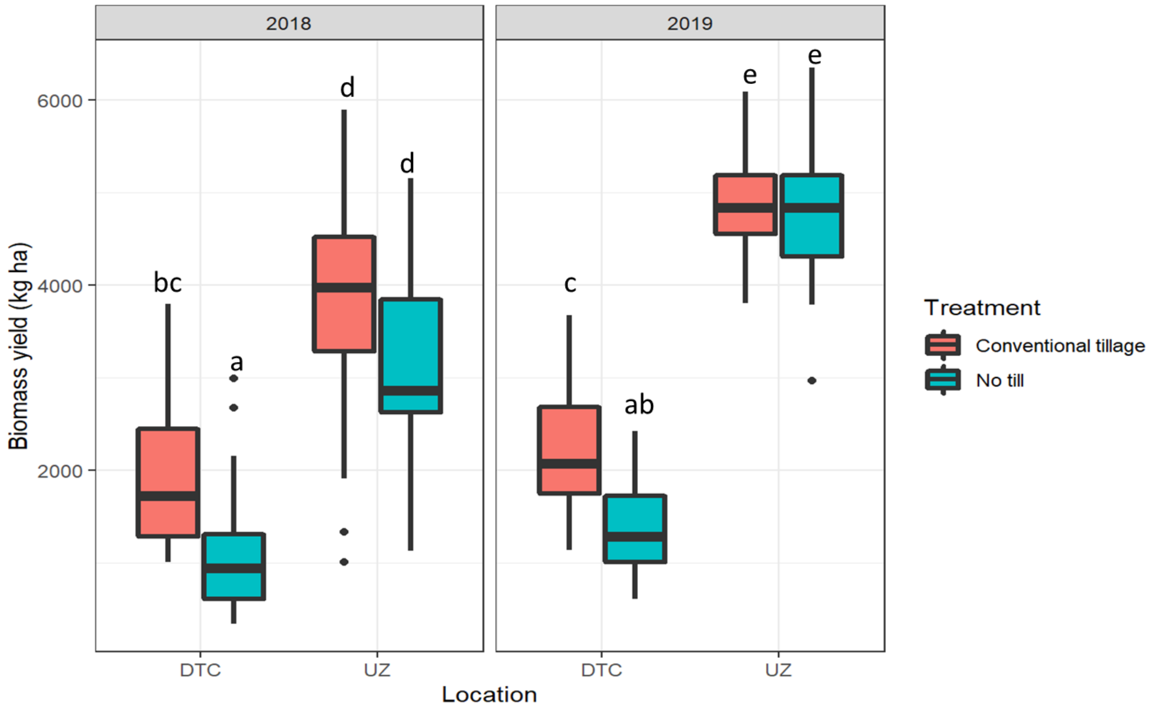

Figure 5.3: Effect of crop residue quality and quantity on biomass grain yield in no-tillage and conventional tillage practices at DTC and UZ farm during 2018 and 2019 cropping seasons

5.5 Discussion

Results show that DTC had lower leaf chlorophyll than UZ. This could be related to differences in soil types between the sites. DTC is dominated by sandy soils with low soil organic matter and soil N (Jones et al., 2013). Hence, the crops depend mostly on the applied fertilisers for plant growth. Results also showed that cropping season quality has an effect on leaf chlorophyll content. These results concur with Sanchez et al. (1983) who reported a decrease in chlorophyll content due to water stress. However, the decrease in chlorophyll content in their study was insufficient to affect photosynthetic activities of the crop during the day. This is probably similar to this study at DTC and UZ. More chlorophyll was observed in conventional tillage than no-till. This could be related to high mineralisation of nutrients due to tillage during the beginning of the experiments, however continuous tillage results in high leaching of the nutrients which reduces crop production (Busari et al., 2015).

Low yields in no-till could have been a result of delayed gratification under minimum soil disturbance. (Thierfelder et al., 2013) supports that long-term conservation agriculture studies have shown that maize yields in the initial years are not significantly different from conventional practices. The benefits of minimum tillage are highly site-specific. Richards et al., (2014) suggests that improvement of the soil structure and fertility is a slow process and increase in yields can be seen after 3 to 7 years. Higher yields in conventional tillage compared to no till could be a result of increased biomass decomposition and nutrient mineralization in ploughed soils (Hendrix et al., 1986).

5.6 Conclusions

Based on the findings from this study, it can be concluded that maize crop chlorophyll content is affected by tillage practices, soil types and the quality of the cropping season. Moisture stress during cropping season reduces chlorophyll content. Conventional tillage practices increases mineralisation of nutrients which increases uptake of N which is the major component of leaf chlorophyll.

Delayed gratification under no-till systems reduces maize stover and grain yield in the early years of practising it. However, in the long run there is more accumulation of organic matter when crop residues are retained which improves crop yields. Thus, management of crop residues in no-till systems is crucial to overcome challenges with moisture stress and nutrients cycling which both influences crop productivity.

5.6 References

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., Giller, K.E., 2012. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Research 132, 117–128. https://doi.org/10.1016/j.fcr.2011.09.008

Busari, M.A., Kukal, S.S., Kaur, A., Bhatt, R., Dulazi, A.A., 2015. Conservation tillage impacts on soil, crop and the environment. International Soil and Water Conservation Research 3, 119–129. https://doi.org/10.1016/j.iswcr.2015.05.002

Duncan, A.J., Bachewe, F., Mekonnen, K., Valbuena, D., Rachier, G., Lule, D., Bahta, M., Erenstein, O., 2016. Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. Agriculture, Ecosystems & Environment 228, 101–110. https://doi.org/10.1016/j.agee.2016.05.011

Hendrix, P.F., Parmelee, R.W., Crossley Jr, D., Coleman, D.C., Odum, E.P., Groffman, P.M., 1986. Detritus food webs in conventional and no-tillage agroecosystems. Bioscience 36, 374–380.

Jones, A., Breuning-Madsen, H., Brossard, A., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R., 2013. Soil atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Kodzwa, J.J., Gotosa, J., Nyamangara, J., 2020. Mulching is the most important of the three conservation agriculture principles in increasing crop yield in the short term, under sub humid tropical conditions in Zimbabwe. Soil and Tillage Research 197, 104515. https://doi.org/10.1016/j.still.2019.104515

Markwell, J., Osterman, J.C., Mitchell, J.L., 1995. Calibration of the Minolta SPAD-502 leaf chlorophyll meter. Photosynthesis research 46, 467–472.

Mupangwa, W., Mutenje, M., Thierfelder, C., Nyagumbo, I., 2017. Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? Renewable Agriculture and Food Systems 32, 87–103.

O’Dell, D., Eash, N.S., Hicks, B.B., Oetting, J.N., Sauer, T.J., Lambert, D.M., Thierfelder, C., Muoni, T., Logan, J., Zahn, J.A., 2020. Conservation agriculture as a climate change mitigation strategy in Zimbabwe. International Journal of Agricultural Sustainability 1–16.

Richards, M., Sapkota, T.B., Stirling, C.M., Thierfelder, C., Verhulst, N., Friedrich, T., Kienzle, J., 2014. Conservation agriculture: Implementation guidance for policymakers and investors.

Rusinamhodzi, L., Corbeels, M., Van Wijk, M.T., Rufino, M.C., Nyamangara, J., Giller, K.E., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agronomy for sustainable development 31, 657.

Rusinamhodzi, L., van Wijk, M.T., Corbeels, M., Rufino, M.C., Giller, K.E., 2015. Maize crop residue uses and trade-offs on smallholder crop-livestock farms in Zimbabwe: Economic implications of intensification. Agriculture, Ecosystems & Environment 214, 31–45.

Sanchez, R., Hall, A., Trapani, N., De Hunau, R.C., 1983. Effects of water stress on the chlorophyll content, nitrogen level and photosynthesis of leaves of two maize genotypes. Photosynthesis research 4, 35–47.

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S., Rusinamhodzi, L., 2013. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crops Research 142, 47–57.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Most smallholder farmers in Zimbabwe depend on natural rainfall, for maize production, which is highly affected by climate change (Alexandratos and Bruinsma, 2012). Thus, good agronomic practices are essential to improve food and nutrition security in smallholder farms. These practices include no till practices which conserves soil through low soil erosion when compared to conventional tillage (Thierfelder et al., 2015). Retention of crop residues in the field, either incorporating them in the soil or spread them on the surface, also has positive impacts on maize production. This study focused on the effect of tillage systems and retention of crop residues strategies (maize and pigeon pea applied at 3 and 6 t ha^{-1}). In no till systems crop residues were spread on the surface due to lack on ploughing in this system and in conventional tillage they were incorporated in the soil.

6.2 Research summary

An on-station experiment was conducted at DTC and UZ farm, rainfed, involving two main treatments namely no till and conventional tillage and four sub-treatments namely no residues, 3 t ha^{-1} maize residues, 3 t ha^{-1} pigeon pea residues and 6 t ha^{-1} maize residues. The sites had contrasting soil types (Jones et al., 2013) and the experiment was conducted in two cropping seasons.

Crop residue retention strategies had a significant effect on water infiltration and soil macrofauna. Tillage systems also had influence on water infiltration and also chlorophyll content as well as maize biomass and grain yield. Other factors including site and season also influence water infiltration and maize yield.

6.3 Conclusions

Although the maize yields were higher in conventional tillage systems than no till systems, there were other benefits of retaining crop residues on the surface which have potential to improve productivity in the long run. High infiltration was observed in no till with crop maize residues, which reduces moisture scarcity problems often faced by smallholder farmers in Zimbabwe. Increase in soil macrofauna was also observed due to retention of crop residues. The macrofauna helps in decomposition of crop residues which releases nutrients that will benefit crop growth. Soil type has an influence on maize chlorophyll content where sandy soils which are commonly poor soils reduce the chlorophyll content of the crop. From these study findings, it can be concluded that no till systems with crop residues spread on the surface has potential to improve maize productivity in smallholder farms in Zimbabwe.

6.4 Policy implication and recommendations

The current efforts to increase farmers' adaptation to climate change can be addressed with practicing no till practices and retention of at least 3 t crop residues ha^{-1}. This will help farmers conserves soil moisture and improve soil fertility status over time. Also there is potential to increase maize yields over time which increase food security in smallholder households.

6.5 Areas for further research

Efforts can be made to investigate how the third principle of conservation agriculture can influence maize yields under similar management practices investigated in this study. Farmers prefer to grow maize in mono-cropping manner for food security reasons, thus practices like intercropping can be further explored to investigate if they can improve maize yields in the short run. Additional data including weather data and in-depth soil analysis could be used to model the influence of these management practices in changing environmental conditions and time.

6.6 References

Alexandratos, N., Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper FAO, Rome.

Jones, A., Breuning-Madsen, H., Brossard, A., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R., 2013. Soil atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Thierfelder, C., Mutenje, M., Mujeyi, A., Mupangwa, W., 2015. Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. Food Secur. 7, 15–31. https://doi.org/10.1007/s12571-014-0404-y

APPENDICES

Appendix 1: Combined analysis of variance for infiltration measurements at DTC and UZ farm

```
##                    Df Sum Sq Mean Sq F value   Pr(>F)
## main                1  0.585  0.5854  16.920 6.22e-05 ***
## sub                 3  0.525  0.1749   5.056  0.00226 **
## year                1  0.291  0.2911   8.413  0.00425 **
## loc                 1  1.067  1.0669  30.836 1.14e-07 ***
## main:sub            3  0.548  0.1828   5.282  0.00169 **
## main:year           1  0.256  0.2562   7.406  0.00722 **
## sub:year            3  0.259  0.0863   2.495  0.06185 .
## main:loc            1  0.385  0.3846  11.116  0.00106 **
## sub:loc             3  0.345  0.1149   3.322  0.02132 *
## year:loc            1  0.159  0.1593   4.604  0.03341 *
## main:sub:year       3  0.339  0.1131   3.270  0.02281 *
## main:sub:loc        3  0.388  0.1293   3.737  0.01245 *
## main:year:loc       1  0.146  0.1456   4.208  0.04187 *
## sub:year:loc        3  0.191  0.0637   1.842  0.14164
## main:sub:year:loc   3  0.265  0.0883   2.551  0.05760 .
## Residuals         160  5.536  0.0346
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix 2: Analysis of Variance for the soil macrofauna density at DTC and UZ farm

```
##                     Df   Sum Sq Mean Sq F value  Pr(>F)    
## main                 1     2178    2178   0.083 0.77405    
## sub                  3   552670  184223   6.979 0.00013 ***
## year                 1    42162   42162   1.597 0.20684    
## loc                  1    26460   26460   1.002 0.31717    
## main:sub             3    80841   26947   1.021 0.38296    
## main:year            1     9735    9735   0.369 0.54391    
## sub:year             3     7541    2514   0.095 0.96266    
## main:loc             1    64178   64178   2.431 0.11952    
## sub:loc              3    57646   19215   0.728 0.53561    
## year:loc             1    19600   19600   0.743 0.38924    
## main:sub:year        3     1092     364   0.014 0.99779    
## main:sub:loc         3   119577   39859   1.510 0.21093    
## main:year:loc        1        2       2   0.000 0.99346    
## sub:year:loc         3    23191    7730   0.293 0.83058    
## main:sub:year:loc   3     6686    2229   0.084 0.96853    
## Residuals          544 14359922   26397                    
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix 3: Analysis of Variance for chlorophyll measurements at DTC and UZ farm

```
##                    Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)    
## main                844.3   844.3     1   928  8.3628 0.0039193 ** 
## sub                  58.9    19.6     3   928  0.1944 0.9002236    
## loc                8909.1  8909.1     1   928 88.2428 < 2.2e-16 ***
## year               3433.4  3433.4     1   928 34.0070 7.577e-09 ***
## main:sub             58.9    19.6     3   928  0.1944 0.9002338    
## main:loc           1189.7  1189.7     1   928 11.7839 0.0006239 ***
## sub:loc             119.7    39.9     3   928  0.3954 0.7563716    
## main:year            46.2    46.2     1   928  0.4580 0.4987093    
## sub:year            114.1    38.0     3   928  0.3767 0.7698291    
## loc:year           8439.0  8439.0     1   928 83.5867 < 2.2e-16 ***
## main:sub:loc        526.5   175.5     3   928  1.7384 0.1574903    
## main:sub:year       184.1    61.4     3   928  0.6080 0.6099099    
## main:loc:year       199.0   199.0     1   928  1.9712 0.1606518    
## sub:loc:year         56.5    18.8     3   928  0.1865 0.9056214    
## main:sub:loc:year    22.7     7.6     3   928  0.0749 0.9734920    
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix 4: Analysis of Variance for maize grain yields for DTC and UZ farm

```
##                         Df    Sum Sq   Mean Sq F value   Pr(>F)
## Treatment                1   7172566   7172566   9.481 0.002444 **
## Sub                      3   1860658    620219   0.820 0.484705
## Year                     1    118244    118244   0.156 0.693117
## loc                      1 194644698 194644698 257.282  < 2e-16 ***
## Treatment:Sub            3    354559    118186   0.156 0.925554
## Treatment:Year           1   1372371   1372371   1.814 0.179933
## Sub:Year                 3   2657298    885766   1.171 0.322682
## Treatment:loc            1   9791156   9791156  12.942 0.000428 ***
## Sub:loc                  3   2692183    897394   1.186 0.316829
## Year:loc                 1   8027187   8027187  10.610 0.001373 **
## Treatment:Sub:Year       3    445219    148406   0.196 0.898890
## Treatment:Sub:loc        3   1526204    508735   0.672 0.570133
## Treatment:Year:loc       1    153375    153375   0.203 0.653135
## Sub:Year:loc             3    348557    116186   0.154 0.927265
## Treatment:Sub:Year:loc   3    351473    117158   0.155 0.926435
## Residuals              160 121046789    756542
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix 5: Analysis of Variance for maize biomass yield at DTC and UZ farm

```
##                         Df    Sum Sq   Mean Sq F value   Pr(>F)
## Treatment                1  18070537  18070537  28.537 3.11e-07 ***
## Sub                      3   1687279    562426   0.888   0.4487
## Year                     1  31576950  31576950  49.866 4.76e-11 ***
## loc                      1 298606221 298606221 471.556  < 2e-16 ***
## Treatment:Sub            3    607773    202591   0.320   0.8110
## Treatment:Year           1    445358    445358   0.703   0.4029
## Sub:Year                 3   3572231   1190744   1.880   0.1350
## Treatment:loc            1   2213686   2213686   3.496   0.0634 .
## Sub:loc                  3   1819303    606434   0.958   0.4143
## Year:loc                 1  12894454  12894454  20.363 1.24e-05 ***
## Treatment:Sub:Year       3    111312     37104   0.059   0.9813
## Treatment:Sub:loc        3   2328061    776020   1.225   0.3023
## Treatment:Year:loc       1    828351    828351   1.308   0.2544
## Sub:Year:loc             3   1890598    630199   0.995   0.3967
## Treatment:Sub:Year:loc   3    490796    163599   0.258   0.8553
## Residuals              160 101317829    633236
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```