

EFFECTS OF GREEN MANURE COVER CROPS ON WEED POPULATION,  
PEARL MILLET AND MAIZE PRODUCTIVITY UNDER CONSERVATION  
AGRICULTURE IN LISELO AND MASHARE NAMIBIA.

A RESEARCH THESIS SUBMITTED IN FULFILMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE (CROP SCIENCE) BY THESIS  
OF  
THE UNIVERSITY OF NAMIBIA

BY

SIMON AMAKALI SIMON

STUDENT NUMBER

201044447

GRADUATION MONTH AND YEAR

APRIL 2019

MAIN SUPERVISOR:

PROF FISSEHA ITANNA

(CROP SCIENCE DEPARTMENT, UNIVERSITY OF NAMIBIA)

CO-SUPERVISOR(S):

DR AWALA SIMON KAMWELE

(CROP SCIENCE DEPARTMENT, UNIVERSITY OF NAMIBIA)

**UNIVERSITY OF NAMIBIA**

**FACULTY OF AGRICULTURE**

**The undersigned certify that they have read and recommended to the Department of Crop Science for acceptance of the thesis entitled:**

**Effects of green manure cover crops on weed population, pearl millet and maize productivity under Conservation Agriculture in Namibia.**

**Approved**

.....

(Chairperson)

.....

Prof FissehaItanna (Supervisor)

.....

DrAwala Simon Kamwele (Supervisor)

## ABSTRACT

Smallholder farming communities of northern Namibia are generally cash-constrained and they are situated in marginal areas where poor soil fertility and land degradation are predominant. They find it difficult to purchase mineral fertilizers and herbicides. There is therefore a need to identify cropping systems that are affordable and can improve their productivity. The integration of green manure cover crops (GMCCs) as rotational crops has been investigated to great lengths in Latin America and reported to improve productivity but information on their use is still scarce in Namibia. Two experiments were set up at two sites, Mashare Irrigation Training Center (MITC) and Liselo Research Station (LRS) having contrasting soil types to investigate the effects of rotating pearl millet and maize with different GMCCs on pearl millet, maize productivity and weed populations over two seasons 2016/2017-2017/2018. In the first experiment, nine different GMCCs were rotated with pearl millet, while maize was rotated with nine GMCCs in the second experiment and their effects in the succeeding season were compared with pearl millet and maize monocropping. At MITC, the highest total weed density was observed in the pearl millet-pigeon pea rotation treatment with 3500 weeds ha<sup>-1</sup> in season 1, P=0.0371 and 6400 weeds ha<sup>-1</sup>, P=0.0451 in season 2. The lowest weed density was observed in the pearl millet-lablab treatment with 1300 weeds ha<sup>-1</sup> and P=0.0371 in season 1 and 2100 weeds ha<sup>-1</sup> and P=0.0451 in season 2. At LRS, the highest total weed density was observed in the maize-pigeon pea rotation treatment with 3200 weeds ha<sup>-1</sup> and P=0.0433 in season 1 and 3300 weeds ha<sup>-1</sup> and P=0.0198 in season 2. While, maize-velvet bean rotation treatment had the lowest weed densities of 900 weeds ha<sup>-1</sup> and P=0.0433 in season 1 and 1000 weeds ha<sup>-1</sup> and P=0.0198 in season 2. Lablab gave the highest biomass yields as high as 12 t ha<sup>-1</sup> both seasons P=0.5929, P=0.4820 at MITC and at LRS velvet bean yielded up to 10 t ha<sup>-1</sup> and P=0.9143 in season 1. The highest plant available nitrogen was produced by jack bean (900 ppm) and P=0.0000 at LRS. Maize grain and biomass yields were significantly P=0.0172 affected by different rotations at LRS in season two with maize after maize monocropping attaining the least grain yield of 2.4 t ha<sup>-1</sup>. In conclusion, rotating pearl millet and maize with cover crops has more noticeable benefits as compared to monocropping and no cover crop could offer all benefits hence this call for identification of niches and a suitable cover crop for that specific niche.,

Key words: Conservation agriculture, cover crops, green manure, crop rotation, weeds

## DECLARATION

This present study was carried out at Mashare Irrigation Training Center (MITC) and at Liselo Research station (LRS) in collaboration with the University of Namibia, Ministry of Agriculture, CIMMYT- Zimbabwe and GIZ, under the supervision of Prof FissehaItanna, and DrAwala Simon Kamwele.

I declare that the research presented in this thesis is original work and has never been submitted in any form at any university. Work that has been done by other researchers and used in this thesis has been acknowledged.

.....

.....

Simon Amakali Simon

Date

## **ACKNOWLEDGEMENTS**

First and foremost, I would like to express my sincere gratitude to my academic supervisors, Prof FissehaItanna, and DrAwala Simon Kamwele for their guidance, mentorship and generosity of their precious time in shaping this work and for seeing the potential in me.

This study was funded by GIZ under the Adaptation to Climate Change in Namibia project (ACN). Special thanks go to Dr. Alexander Schöning for giving me the opportunity to be part of the project and for supporting me throughout the study. Particular thanks go to Prof Fisseha Itanna who first realized the potential in me and motivated me to undertake my Master study and supported me in every way possible to make sure that I achieve international standard research. I am short of words to explain how he made everything easy for me, from organizing funding of my tuition fees to writing of this work. I am forever indebted for the generosity of his time in vigilantly reviewing my work and picking all the mistakes to shape it into a fine piece of work. His great contributions, constructive criticisms and ideas shaped this work into what it is now, thank you so much. I am grateful to Dr. Christian Thierfelder for his energy, enthusiasm, and encouragement over the last two years and for his diligence and kindness in guiding me through the research process. I thank Mrs. Margret Bartels for her technical and logistical support to make the research a success.

I am thankful to the University of Namibia, Crop Science Department for considering my research worth undertaking.

To my grandmother and the rest of the Amakali family, thank you very much for your prayers and support during the course of the study, it is through these that I triumphed the hard times. To Monica Uugwanga, you are my inspiration, thank you for being there for me.

I thank my friends Ladislaus, Kristofina, Albertina, Veronica, Agnes, Titus, Paul, Bethold and Timo for their encouragement.

## LIST OF TABLES

Table 1: Linear mixed model (combined model) output explaining the effects of different pearl millet and maize-cover crop rotations (treatment) and site on total weed density, total weed biomass, weed species diversity, weed species evenness and weed species richness at both sites for both seasons.....	49
Table 2: Effect of different pearl millet and maize-cover crop rotations on weed species diversity (Shannon's index 'H') and weed species evenness (Shannon's index 'E') at both sites for both seasons.....	55
Table 3: Soil nitrogen, phosphorous, potassium, pH, organic carbon, and soil organic matter levels at both sites.....	61

## LIST OF FIGURES

Figure 1: Average annual rainfall in Namibia (Source: FAO, 2013b).....	2
Figure 2: Baufi ripper.....	15
Figure 3: The Li seeder®. ....	17
Figure 4: The geographical location of MITC and LRS in Namibia. ....	34
Figure 5: The distribution of rainfall at both experimental sites, Liselo research Station (2016/2017-2017/2018) and Mashare Irrigation Training Centre (2016/2017-2017/2018). ....	<b>Error! Bookmark not defined.</b>
Figure 6: The effects of different pearl millet-cover crop rotations on total weed density at MITC in season one of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the first season. ....	45
Figure 7: The effects of different pearl millet-cover crop rotations on total weed density at MITC in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2017/2018). ....	46
Figure 8: The effects of different pearl millet-cover crop rotations on total weed density at MITC in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2016/2017). ....	47
Figure 9: The effects of different maize-cover crop rotations on total weed density at LRS in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2017/2018). ....	48
Figure 10: The effects of different pearl millet-cover crop rotations on total weed biomass at MITC in the first season of data collection. ....	50
Figure 11: The effects of different pearl millet-cover crop rotations on total weed biomass at MITC in the second season of data collection. ....	51
Figure 12: The effects of different maize-cover crop rotations on total weed biomass at LRS in the first season of data collection. ....	52

Figure 13: The effects of different maize-cover crop rotations on total weed biomass at LRS in the second season of data collection. ....	53
Figure 14: The effects of different Pearl millet-cover crop rotations on weed species richness at MITC in both seasons of data collection. The different columns signify differences in the effects of the different rotations ( $P < 0.05$ ) on weed species richness in each season. ....	56
Figure 15: The effects of different pearl millet-cover crop rotations on weed species richness at MITC in the second season of data collection. The different column signifies differences in the effects of the different rotations ( $P < 0.05$ ) on weed species richness in the second season. ....	57
Figure 16: The effects of different maize-cover crop rotations on weed species richness at LRS in the first season of data collection. ....	57
Figure 17: The effects of different maize-cover crop rotations on weed species richness at LRS in the second season of data collection. ....	58
Figure 18: Predominant weed species at MITC and LRS in all the treatments for both seasons. ....	58
Figure 19: Effects of different pearl millet-cover crop rotations on grain and biomass yields ( $\text{kg ha}^{-1}$ ) of cover crops in both seasons at MITC. Means represented by columns are significantly different using the LSD test ( $P < 0.05$ ). ....	59
Figure 20: Effects of different maize-cover crop rotations on grain and biomass yields ( $\text{kg ha}^{-1}$ ) of cover crops in both seasons at LRS. Means represented by columns indicated by different bars are significantly different using the LSD test ( $P < 0.05$ ). ....	60
Figure 21: Effects of different pearl millet-cover crop rotations on PAN (ppm) contribution of different cover crop residue to the succeeding pearl millet crop in both seasons at MITC. Means represented by columns indicated by different letters are significantly different using the LSD test in the first season ( $p > 0.05$ ). ....	63
Figure 22: Effects of different maize-cover crop rotations on PAN (ppm) contribution of different cover crop residue to the succeeding maize crop in both seasons at LRS. Means represented by bars indicated by different letters are significantly different using the LSD test in the first season ( $P < 0.05$ ). ....	63

Figure 23: Effects of different pearl millet-cover crop rotations on grain and biomass yields (kg ha-1) of cover crops in season 2 at MITC. Means represented by columns indicated by different bars are significantly different using the LSD test ( $P < 0.05$ ). ..... 65

Figure 24: Effects of different maize-cover crop rotations on grain and stover yields (kg ha-1) of the subsequent maize crop in season 2 at LRS..... 66

## LIST OF APPENDICES

Appendix 1: Analysis of variance for total weed density at MITC in season 1 (Experiment 1).....	99
Appendix 2: Appendix 2: Analysis of variance for total weed density at MITC in season 2 (Experiment 2).....	99
Appendix 3: Analysis of variance for total weed density at LRS in season 1 (Experiment 1).....	99
Appendix 4: Appendix 4: Analysis of variance for total weed density at LRS in season 2 (Experiment 1).....	100
Appendix 5: Analysis of variance for total weed biomass at MITC in season 1 (Experiment 1).....	100
Appendix 6: Analysis of variance for total weed biomass at MITC in season 2 (Experiment 2).....	100
Appendix 7: Analysis of variance for total weed biomass at LRS in season 1 (Experiment 1).....	101
Appendix 8: Analysis of variance for total weed biomass at LRS in season 2 (Experiment 2).....	101
Appendix 9: Analysis of variance for weed species diversity at MITC in season 1 (Experiment 1).....	101
Appendix 10: Analysis of variance for weed species diversity at MITC in season 2 (Experiment 2).....	102
Appendix 11: Analysis of variance for weed species diversity at LRS in season 1 (Experiment 1).....	102

Appendix 12: Analysis of variance for weed diversity at LRS in season 2 (Experiment 2)	102
.....	102
Appendix 13: Analysis of variance for weed species evenness at MITC in season 1 (Experiment 1)	103
.....	103
Appendix 14: Analysis of variance for weed species evenness at MITC in season 2 (Experiment 2)	103
.....	103
Appendix 15: Analysis of variance for weed species evenness at LRS in season 1 (Experiment 1)	103
.....	103
Appendix 16: Analysis of variance for weed species evenness at LRS in season	104
.....	104
Appendix 17: Analysis of variance for weed species richness at MITC in season 1 (Experiment 1)	104
.....	104
Appendix 18: Analysis of variance for weed species richness at MITC in season 2 (Experiment 2)	104
.....	104
Appendix 19: Analysis of variance for weed species richness at LRS in season 1 (Experiment 1)	105
.....	105
Appendix 20: Analysis of variance for weed species richness at LRS in season 2 (Experiment 2)	105
.....	105
Appendix 21: Analysis of variance for GMCC grain yield at MITC in season 1 (Experiment 1)	105
.....	105
Appendix 22: Analysis of variance for grain yield at LRS in season 1 (Experiment 1)	106
.....	106
Appendix 23: Analysis of variance for GMCC biomass yield at MITC in season 1 (Experiment 1)	106
.....	106

Appendix 24: Analysis of variance for GMCC biomass yield at LRS in season 1 (Experiment 1).....	106
Appendix 25: Analysis of variance for PAN at MITC in season 2 (Experiment 2) .....	107
Appendix 26: Analysis of variance for PAN at LRS in season 2 (Experiment 2) .....	107
Appendix 27: Analysis of variance for pearl millet grain yield at MITC in season 2 (Experiment 1).....	107
Appendix 28: Analysis of variance for maize grain yield at LRS in season 2 (Experiment 2).....	108
Appendix 29: Analysis of variance for pearl millet stover yield at MITC in season 2 (Experiment1).....	108
Appendix 30: Analysis of variance for maize stover yield at LRS in season 2 (Experiment 2).....	108
Appendix 31: Analysis of variance for supplementary biomass quantity at MITC at end of season 2 (Experiment 2).....	109
Appendix 32: Analysis of variance for supplementary biomass quantity at LRS at end of season 2 (Experiment 2).....	109
Appendix 33: Analysis of variance for supplementary biomass quantity at MITC at end of season 1 (Experiment 1).....	109
Appendix 34: Analysis of variance for supplementary biomass quantity at LRS at end of season 2 (Experiment 2).....	110

Appendix 35: Analysis of variance for percentage contact ground cover at MITC in March of season 1 (Experiment 1).....110

Appendix 36: Analysis of variance for percentage contact ground cover at MITC in March of season 2 (Experiment 2).....110

Appendix 37: Analysis of variance for percentage contact ground cover at MITC in June of season 1 (Experiment 1).....111

Appendix 38: Analysis of variance for percentage contact ground cover at MITC in June of season 2 (Experiment 2).....111

Appendix 39: Analysis of variance for percentage contact ground cover at LRS in March of season 1 (Experiment 1).....111

Appendix 40: Analysis of variance for percentage contact ground cover at LRS in March of season 2 (Experiment 2).....112

Appendix 41: Analysis of variance for percentage contact ground cover at LRS in June of season 1 (Experiment 1).....112

Appendix 42: Analysis of variance for percentage ground cover at LRS in June of season 2 (Experiment 2).....112

## LIST OF ABBREVIATIONS

%	Percentage
ACDI/VOCA	Agricultural Cooperative Development International
AN	Ammonium nitrate
ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
C: N	Carbon to Nitrogen Ratio
CA	Conservation agriculture
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre
cm	Centimeter
CP	Crude protein
DAPM	Days after planting maize
DM	dry matter
FAO	Food and Agriculture Organization
FEWS	NET Famine Early Warning Systems Network
$\text{g m}^{-2}$	grams per square metre
GMCCs	Green Manure Cover Crops
HIV/ AIDS Syndrome	Human Immunodeficiency Virus/Acquired Immuno Deficiency
$\text{kg ha}^{-1}$	kilogram per hectare

kg K ha <sup>-1</sup>	kilograms potassium per hectare
kg N ha <sup>-1</sup>	kilograms nitrogen per hectare
kg P ha <sup>-1</sup>	kilograms phosphorus per hectare
l ha <sup>-1</sup>	Litres per hectare
LER	Land Equivalent Ratio
LRS	Liselo Research Station
LSD	Least Significant Difference
M	Meter
m <sup>-2</sup>	Per square meter
MITC	Mashare Irrigation Training Center
Mm	Millimeter
N	Nitrogen
NS	Not significant
PAN	Plant-available soil nitrogen
SEM	Standard Error of Mean
SSA	sub-Saharan Africa
t ha <sup>-1</sup>	Tons per hectare
UNAM	University of Namibia
ZCATF	Zimbabwe Conservation Agriculture Task Force

## TABLE OF CONTENTS

ABSTRACT .....	II
DECLARATION .....	III
ACKNOWLEDGEMENTS .....	IV
LIST OF TABLES .....	V
LIST OF FIGURES .....	VI
LIST OF APPENDICES .....	IX
LIST OF ABBREVIATIONS .....	XIII
1.0 INTRODUCTION .....	<b>Error! Bookmark not defined.</b>
1.1 Background of the study.....	1
1.2 Statement of the problem .....	9
1.3 Objectives .....	9
1.3.1 Overall objectives .....	9
1.3.2 Specific objectives .....	10
1.4 Hypothesis .....	10
1.5 Significance of the study .....	10
2.0 LITERATURE REVIEW .....	11
2.1 The State and Possible Causes of Food Insecurity in Namibia.....	11
2.2 Conservation Agriculture (CA) – Origin, definition and principles .....	14
2.2.1 Definition and principles of CA .....	14
2.2.1.1 Minimum soil disturbance .....	14
2.2.1.2 Permanent soil cover.....	18
2.2.1.3 Diversification of crop rotations and plant associations .....	18
2.3 Benefits of CA.....	19
2.4 Challenges of CA and Impact on Adoption Rates .....	20

2.4.1 Weed definition.....	20
2.4.2 Residues retention.....	26
2.4.3 Nitrogen management.....	26
2.5 The potential use of GMCCs as Weed and Nitrogen management tools .....	27
2.6 Characteristics of the possible GMCCs used under CA.....	28
2.6.2 <i>Crotalaria</i> species.....	28
2.6.3 <i>Mucuna pruriens</i> (Velvet bean).....	29
2.6.4 <i>Vigna unguiculata</i> (Cowpea) .....	29
2.6.5 <i>Lablab purpureus</i> Sweet (Lablab) .....	30
2.6.6 <i>Canavalia ensiformis</i> (Jack bean) .....	30
2.6.7 <i>Raphanus sativus</i> (Fodder radish).....	30
2.6.8 <i>Vicia villosa</i> (Hairy vetch).....	30
2.6.9 <i>Lupinus angustifolius</i> (Blue lupine) .....	31
2.7 Rotations of GMCCs in Cropping Systems as a Residue Management Strategy .....	31
2.8 General overview of GMCC use in Pearl millet and Maize-based Cropping Systems.....	32
3.0 MATERIALS AND METHODS .....	33
3.1 Site description .....	33
3.2 General Study Descriptions.....	35
3.2.1 Background of the Trial.....	35
3.2.1 Trial description.....	35
3.3 Field Measurements .....	37
3.3.1 Weed biomass and density.....	37
3.3.2 Green Manure Cover Crop Biomass Yields .....	37
3.3.3 Pearl Millet, Maize and Biomass (Stover) Yields .....	38

3.4 Plot management .....	38
3.4.1 Fertilizer application .....	38
3.4.2 Weed control.....	39
3.4.3 Residue management .....	39
3.5 Data collected .....	39
3.5.1 Weed counts, biomass and species composition .....	39
3.5.2 Plant available nitrogen (PAN) contribution by GMCCs.....	40
3.5.3 GMCC grain and biomass yield.....	40
3.5.4 Pearl millet, maize grain and stover yield.....	41
3.6 Statistical Analysis .....	41
4.0 RESULTS .....	42
4.1 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on total weed density, total weed biomass and weed composition. ....	42
4.1.1 Total weed density .....	43
4.1.2 Total weed biomass .....	49
4.1.3 Weed species composition (Weed species diversity, evenness and richness).....	54
4.1.4 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on GMCC grain and biomass yield.....	58
4.1.5 Soil fertility .....	61
4.1.6 Effects of different rotations on soil PAN contribution from GMCC residues .....	62
4.1.7 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on grain and stover yields of the subsequent maize crop .....	64
5.0 DISCUSSIONS .....	67
5.1 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on total weed density, total weed biomass and composition.....	67
5.1.1 Total weed density .....	67

5.1.2 Total weed biomass .....	68
5.1.3 Weed composition (Weed species diversity, evenness and richness) .....	68
5.1.4 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on GMCC grain and biomass yields. ....	69
5.1.5 Effects of different rotations on PAN contribution from GMCC residue .....	70
5.1.6 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on grain and stover yields of the subsequent pearl millet and maize crop. ....	70
5.1.7 Limitations to the study .....	71
6.0 CONCLUSION AND RECOMMENDATION .....	74
REFERENCES.....	78
LIST OF APPENDICES.....	99

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background of the study

The world's population is expected to have more than tripled by the year 2050 yet the current agricultural production is not able to sustain the present-day population (FAO, 2009). Smallholder farmers in sub-Saharan Africa (SSA) are failing to produce enough food due to poor soil fertility and land degradation (Tittonell *et al.*, 2012). Most of the smallholder farmers are dependent on agriculture for food and hence affected by these problems triggered by poor investment and downgraded agricultural landscape (FAO, 2013b). The SSA poorest people depend on small scale farming as their only source of food and in a contest to feed the ever growing population, unsustainable human activities have caused increased burden on the land resulting to the degradation of the land, such as the tilling of the land with no plans to preserve the soil (Bogdanski, 2012c). The food production per capita in Africa has been reported to be declining over the past 50 years (FAO, 2012). Furthermore, food security among small scale farmers in Southern Africa remains moderately low due to the low implementation of enhanced knowledge and technology such as fertilizer, improved pearl millet (*Pennisetum glaucum* (L) R. Br), maize (*Zea mays* L.) seeds, legume varieties and soil degrading cropping practices (Thierfelder, C., Cheesman, S., Rusinamhodzi, L., 2013).

In the report by FAO (2009), Namibia was named as the driest country south of the Sahara desert and the country experiences unbalanced drought and floods. FAO further reported that, although Namibia is rich in natural resources, water, which is a prerequisite for human, animal and plant life is in short supply. FAO (2014) also stated that, the devastating two main features of Namibia's climate are the scarcity and irregularity of rainfall. The mean annual rainfall in the country ranges from less than 50 mm per annum in the western region along the coastline to a maximum of 700 mm per annum in north eastern Zambezi (Derpsch, 2008). Only 8% of Namibia's total land area receives rainfall of 500 mm per annum or above, and in broad-spectrum the rainfall is uneven throughout most parts of the country (Heyns, 1991).

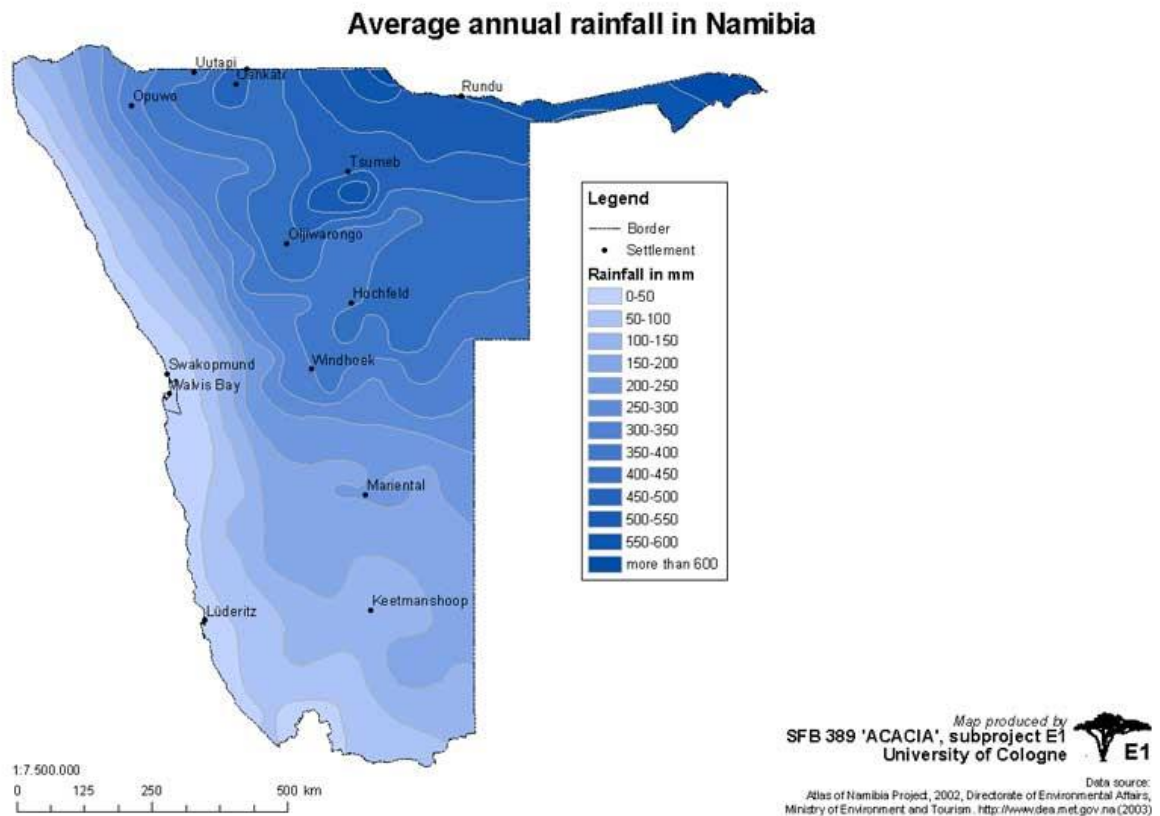


Figure 1: Average annual rainfall in Namibia (Source: FAO, 2013b).

Mc Donagh & Hillyer (2003) stated that Namibian soils are sandy, stony and shallow, with low organic matter, clay content, and with a low water retention capacity. They further indicated that most of the Namibian soils lack most of the important nutrients especially phosphorous and nitrogen. In the face of climate change to which humans play a big part, the challenge for Namibian crop farmers is to end further degradation of the soil (FAO, 2014). This challenge is increased by the fact that the vast majority of the farmers' are currently practicing conventional cultivation practices (CP) which are also contributing vastly to poor soil fertility, water retention capacity and compaction of the soil (Derpsch, 2009).

Kaurivi, J. Z. U., Meroro, A., Mudamburi B., & Namalambo, E. (2010) reported that in the customary Namibian agricultural set-up, pearl millet is the main staple crop in northern, central and eastern farming communities, while in the Zambezi Region, maize is the predominant staple crop. Both are rarely complimented with other vegetables, in the food habits of Namibians. Agricultural production in this arid country is hindered by low and unreliable rainfall and naturally poor soils Kuvare, U, Maharero, T and Kamupingene, G. (2008). However, despite the marginal (5.1%) contribution of agriculture to the Gross Domestic Product (GDP), the sector supports over 70% of the country's population (FAO, 2014). The main contributing factors to food insecurity and under-nourishment are the high poverty rate, inequality of the income distribution, and the predominance of the HIV/AIDS pandemic. Other comprehensive factors affecting small scale farmers in the country include: prolonged drought and subsequently leading to water shortages, which results in the death of farmers livestock and total crop failures, prevailing soil erosion and land the continuers soil degradation, lack of fertile agricultural land and isolation from of smallholder farmers from the local and international markets, limited income making opportunities, limitations on women to own land and properties, and lack of application of suitable and sustainable government agricultural policies (FAO, 2014).

In rural Namibia, the majority of the population is affected by a combination of low food production yield, food insecurity and sustainable living condition challenges (FAO, 2012b). This is caused by low agricultural output as a result of deteriorating soil quality and unsustainable cropping systems (Donovan and Casey, 1998; Mupangwa & Twomlow, 2000). High population densities and low investment in the agricultural sector have led to complications of land degradation and poverty (Whitlow, 1987).

Most smallholder farmers in Namibia still use the traditional moldboard plough and the hand hoe for land preparation in their agricultural set-up and this farming system, and type of farming is known as conventional tillage (Baudron *et al.*, 2001). Conventional tillage involves the overturning of the soil at the beginning of the season for planting purposes, and to control weeds in the same season in order to control weeds (Muza *et al.*, 1996). The main reason why these small scale farmers turn over the soil at the

beginning of the season is the easiness with which the practice controls weeds, since weeds are buried, leaving the fields clean (Muza *et al.*, 1996). Farmers also till the land to bury crop residues since. This allows the incorporation of crop residues in the soil, and it also helps with the decomposition of the residues faster hence leading to faster nutrient discharge and organic matter build-up (Kriauciuniene *et al.*, 2012).

These conventional land preparation practices have resulted in the disturbance of the soil, and change the soil structure negatively, leading to soil erosion, soil compaction and a reduction in the yields (Thierfelder & Wall, 2010). With the increasing threat of climate change, the test today is to find sustainable, ecological ways to increase agricultural productivity in order to meet the demands of the ever growing population. In this context, Conservation Agriculture (CA) is fascinating the farming community based on perceptions that it has the potential to moderate the impacts of climate change on farm productivity, reduce the loss of important rainfall and conserve the top soil, adapt more efficiently to hostile weather conditions, improve the health standard of their soils, and reduce the labor and input costs (Teasdale *et al.*, 2007).

The Namibian government Vision 2030 and the fourth Namibian development plan have put pressure on the Government of the Republic of Namibia (GRN) to initiate programs and projects that promotes food security, both at national and household levels (Kuvare *et al.*, 2008). The Vision provides a plan for the growth of the country and it identifies the long term national vision for the country, an inclusive cohesive vision that will assist to direct the country's five-year National Development Plans (NDP) i.e. NPD2 to NPD7. Currently, the Namibian Government has implemented the NDP5 and one of the NDP's main development goals is the eradication of poverty by coming up with sustainable agricultural practices, such as Conventional Agriculture (CA). It is clearly illustrated in NDP4 that the land should be used sustainably, in order for it to contribute significantly towards food security at household and national levels, and contributing towards sustainable growth of the Namibian economy, whilst maintaining and improving land capability (FAO, 2009). CA can help to increase crop yields and therefore be able to get rid of poverty and hunger among smallholder farmers in the country (FAO, 2012c).

FAO (2002) defines CA as a model for resource-saving agricultural knowhow that attempts to achieve acceptable profits together with high and sustained production levels while at the same time conserving the environment.

CA can be better explained as a crop management system based on four basic principles:

- Minimum soil disturbance (i.e. disturb the soil as little as possible) or no soil overturning during tillage at all;
- Permanent soil cover with crop residues and/or living plants;
- Crop rotations to prevent pest and diseases or intercrop and rotate crop; and

For the benefits of CA to be fully realized, the system should be adopted as a full package rather than adopting some of the principles (FAO, 2013a). Thierfelder & Wall (2010) argue that CA has been reported to improve soil properties, which include increasing soil bulk density and macro porosity, reducing soil erosion, decreasing production costs and over-all improving the crop yields. However, challenges related to mulch retention, nitrogen management and weed control have contributed to the slow implementation of CA as a full package by small scale farmers (Thierfelder & Wall, 2008). There appears to be a competition in the use of mulch, between its uses as ground cover and as livestock feed, leading to less than sufficient residue amounts being left for ground cover (Dubreil, 2011).

Brazil has been reported as the country with the longest experience with CA in the world (Bolliger *et al.*, 2006). Ever since the 1970s, Brazil took advantage toward adopting CA when herbicides and direct seeding technology became available in the United States of America (USA), by sending their farmers to the United States to learn about different soil conservation technologies and management systems. Interest groups were established amongst large scale farmers and then later with small scale farmers. CA adoption in Brazil has grown over the years or emerged above all as a result of farmer modernization of the system together with problem-solving support research and extension organizations (FAO, 2013a).

In Argentina, CA has been found to be a suitable alternative to conventional tillage agriculture, and has proven to be more environmentally friendly, maintaining yields and reducing production costs without harming the environment. Most favorable observations were noticed when it includes not only minimum tillage, rotations and cover crops but also the incorporation of insect pest and disease management and nutrient refurbishment. It has been reported that agronomic ecosystems were no longer vulnerable and productive areas have been extended without experiencing some common risks. In addition, soil improvement has increased due to better chemical and physical composition of the soil fertility and more efficient water usage (FAO, 2008a).

Thierfelder *et al.*, (2008) reported that there has been an increase in the number of small scale farmers' uptake of sustainable agriculture in SSA, over the past two decades, that includes the practice of CA. A number of farmers can start practicing this improved farming technology if there is advanced access to manufacturing inputs especially improved seeds and fertilizers, extension and advisory and profitable markets (Tiftonell *et al.*, 2012). There is enough evidence from a number of pilot studies and projects done in the sub-Saharan region that the interventions of CA can indeed achieve remarkable results within a 2-3 year period, especially if access to financing to acquire inputs and farmers' establishments are also improved. These are important interventions that every African government should take up in order to fast track what can uniquely become the African Green Revolution, one that not only increases smallholder agricultural productivity but also conserves the environment (Teasdale *et al.*, 2007a).

A number of challenges experienced in CA such as the retention of mulch, nitrogen management and weed control have contributed to the slow adoption of CA as a full package by small scale farmers' (Thierfelder & Wall, 2008). It was reported that, there appears to be a competition in the use of mulching material, between its uses as ground cover and as livestock feed, leading to less than enough residue amounts being left for ground cover (Dubreil, 2011). Different researches suggested a number of different approaches, to make sure that enough availability of residues for both ground cover in maize-based and pearl millet systems and livestock feed. This includes the rotations with leguminous or non-leguminous green manure cover crops (GMCCs) and/or fodder

crops (FAO, 2012c). In pearl millet and maize-based systems, this could be delay in the planting of these GMCCs and/or fodder crops at a time when the cereal crop starts to die, or rotating them with pearl millet/maize. However, in instance where arable land is of limited quantity small scale farmers would not find it practical to practice crop rotations with GMCCs that do not yield consumable grain materials and have limited markets (Thierfelder *et al.*, 2012). In such cases, farmers may start incorporating grain legumes in their farming system, but only those legumes which contribute to food security while at the same time adding nitrogen to the cropping system should be considered e.g. pigeon pea. Farmers can also start to incorporate GMCCs as relay crops, which only make use of a small portion of the main season without completely replacing the main crop.

Nitrogen is a very important macro nutrient and it has a direct impact on both the legume and cereal crop yield, so its management is significant in smallholder farming unit (Uchida, 2000). Nitrogen can be added to the cropping systems in the form of mineral or chemical fertilizers and sufficient supplies of these mineral fertilizers to pearl millet and maize-based systems under CA is an important measure to ensure improved crop yields in SSA (Vanlauwe *et al.*, 2014). With respect to nitrogen management in Namibia, fertilizer consumption by smallholder farmers is low due to the high prices and usually inaccessibility of these mineral fertilizers by small scale farmers (Mapfumo, P., Mtambanengwe, F., Vanlauwe, B, 2007) leading to low crop yields. There is need to come up with affordable soil preparation practices that can add nitrogen to pearl millet and maize cropping systems for the poor smallholder farmers who cannot afford mineral fertilizers or herbicides. This will then include the rotating of pearl millet and maize with good quality leguminous green manure cover crops (GMCCs) or fodder crops which fix atmospheric nitrogen biologically and have a low C: N ratio which subsequently leads to a timely release of nitrogen into the soil (Olofsson & Oksanen, 2000; Gentile *et al.*, 2009).

The management of weeds have been reported to be one of the main challenges that is experienced by smallholder farmers have adopted and practicing CA. This was especially observed in the first three years of adopting the CA farming system (Goeb,

2013). A reduction in soil tillage exposes weed seeds to a number of weed inducing factors, such as predation of birds and this can lead to the depleting weed seeds in the weed seed bank (Mall and Singh, 2014). A reduction in the tillage of the soil can be quite weed infested and a number of authors have suggested that conservation agriculture promotes perennial grasses (Gan *et al.*, 2008). In addition. They also argue that small seeded weeds have a higher chance of emergence in a minimum tillage farming systems, the reason being that weed seeds are not buried deep in to the soil, to a substantial depth that can inhibit their emergence (Légère *et al.*, 1993).

The variations in weed dynamics, when farmers move to reduced tillage necessitate the smallholder farmers to be more knowledgeable of the new weed species that may emerge in their new farming system in order to be able to control them effectively (Derpsch & Friedrich, 2008). Some commercial farmers under CA have decided to turn to the use of herbicides in in order to control weeds in the first three years of adopting the system. However, synthetic herbicides are expensive and normally not affordable nor accessible to the poor small scale farmers (Wall, 2007). The use of herbicide may also be risky to the less knowledgeable farmers and they may also pose a risk to the surrounding environment (Reganold, J.P., Glover, J.D., Andrews, P.K., Hinman, H.R, 2001). The use of a hand hoe, which is the most common weed control mechanism known to most smallholder farmers is seen as the answer to their weed challengers, however, it is labour intensive, yet labour is a limited commodity in the smallholder farming set up due to the unavailability of young and able bodied, as most of the young people migrate to towns and cities, leaving the old people and the younger kids to work the land, leading to untimely weeding hence low yields (Mandumbu, R., Jowa, P., Karavina, C., Tibugari, H, 2011).

Indeed, there is need to identify a number of different strategies that can provide assistance to weed management while being less laborious and more much more affordable to the poor smallholder farmers. This will there include the use of GMCCs either as live crops or the use of their residues. According to a number of literatures, GMCCs such as sunnhemp (*Crotalaria juncea*) and velvet bean (*Mucuna pruriens*) have been reported over the years to have an oppressive effect on different weed species,

these cover crops either produce allelochemicals that kill the weeds or they have a vigorous growing habit, that allows them to compete for essential growth elements with the different weeds in their surrounding (Teasdale *et al.*, 2007). In addition, GMCCs also have a smothering effect on the weeds, which can lead to the depletion of the weed seed bank, eventually leading to fewer weeds species (FAO, 2010). The advantage or the potential of GMCCs as rotational crops is known, however strategies for the actual integration of these cover crops into the CA systems of southern Africa to contribute to the supplementation of nitrogen, biomass supplementation and weed smothering needs to be investigated. Research needs to be formulated and conducted to optimize the use of these cover crops in smallholder CA systems of southern Africa.

## **1.2 Statement of the problem**

Smallholder farmers in north-central and north-east Namibia attribute their pearl millet and maize yield losses to weed competition and poor soil quality (Kuvare, U, Maharero, T and Kamupingene, 2008). These farmers are generally cash-constrained and situated in marginal areas where poor soil fertility and land degradation are predominant. It is then difficult for these smallholder farmers to purchase mineral fertilizers and herbicides (Mhlanga, B., Cheesman, S., Maasdorp, B., Mupangwa, W., Thierfelder, C, 2014). There is a need to identify cropping systems that are affordable and can improve their productivity. This study will investigate different weed control measures, using different cover crops which have the potential to suppress weed growth, while improving the soil nitrogen content (Kaurivi *et al.*, 2010).

## **1.3 Objectives**

### **1.3.1 Overall objectives**

The purpose of this study was to evaluate the effectiveness of different leguminous and non-leguminous GMCCs/ fodder crops, grown in rotation with pearl millet and maize, in ensuring suitable residue cover and significant fodder supply and to quantify their effects on pearl millet, maize productivity and weed suppression under CA.

### **1.3.2 Specific objectives were to:**

1. Determine the effect of different GMCCs on weed suppression;
2. Determine the weed species diversity, evenness and richness in the various GMCC treatments;
3. Evaluate the effect of GMCCs on plant-available soil nitrogen (PAN); and
4. Assess the effects of GMCCs on above-ground biomass and grain production of pearl millet and maize crops.

### **1.4 Hypothesis**

H<sub>01</sub>=There is no significant difference on the effect of different GMCCs on weed suppression.

H<sub>02</sub>= There is no significant difference on the weed species diversity, evenness and richness in the various GMCC treatments.

H<sub>03</sub>= There is no significant difference on the effect of the different GMCCs on the plant-available soil nitrogen (PAN).

H<sub>04</sub>= There is no significant difference on the effects of GMCCs on above-ground biomass and grain production of pearl millet and maize crops.

### **1.5 Significance of the study**

Herbicides and mineral fertilizers are not commonly used. They are not easily available in rural areas and knowledge about safe use is lacking. The use of cover crops to suppress weeds and at the same time improve the soil quality can be an interesting alternative to successfully reduce the costs of labour and the cost incurred by using chemicals or mechanical practices. Furthermore, this cover crop method is organic and does not have negative environmental impacts. In addition leguminous green manure cover crops can contribute to improving the soils nutrient content, reducing the need for other inputs, thereby increasing land productivity and crop output. The study intends to help farmers that are converting from conventional agriculture to conservation agriculture.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 The State and Possible Causes of Food Insecurity in Namibia

The Namibian economy mainly depend on the agriculture sector and the sector contributes 6–10% to the country's gross domestic product (GDP) (NSA, 2014). The Namibian agricultural sector is classified as a subsistence farming sector, hence the smallholder productivity is very low compared to that of large scale commercial farmers' (Kuvare *et al.*, 2008). In rural Namibia, household food security is obtained from different sources, such as; the domestic food production from farmers' fields, food purchased or sourced from super markets and wholesalers, the government feeding programs and also bartering with neighbors (FAO, 2012). (Kaurivi *et al.*, 2010) reported that the yields of pearl millet (*Pennisetum glaucum*) production on small scale farms are at about 250-400 kg ha<sup>-1</sup> per annum. Equally important, the Namibia Early Warning and Food Information System (NEWFIS, 1993) estimates that the average pearl millet yield to be between 225 and 350 kg ha<sup>-1</sup> per annum. On the other hand, the average maize yield for subsistence farmers was also estimated to be ranging between 500-550 kg ha<sup>-1</sup> in the 2008/09 season, while an average yields of 3.87 t ha<sup>-1</sup> in the commercial sector was recorded (FAO, 2009).

The State of Food Insecurity in the World (2015) reported that around 40 %the Namibian population was estimated to be susceptible to food shortage in Namibia, and according to (FAO, 2009) 42.7% of the population was undernourished in 2014. The Global Hunger Index which is responsible for the measure of hunger levels of the world's countries in 2014 ranked Namibia at position 51 out of 120 countries. NSA (2015) also claimed that from the 2013/14 Census of Agriculture, 76 % of the small scale rural family unit were reported to have experienced food shortages. A large number of these households experienced a major food unavailability in the month of January than any other month of the year. NSA (2015) also argues that the loss of crops experienced by smallholder farmers was mainly due to drought, soil erosion, floods, poor weed management, soil degradation and climate change. A considerable large part

of the Namibian population depends on small scale agriculture and low or no wages for its existence (IFAD, 2015).

The Ministry of Health and Social Services (MoHSS, 2014), reported that Namibia had an adult HIV predominance rate of about 18.8% in 2010, and the country was rated among the top 10 countries with the uppermost HIV incidence rates in the world. It was also estimated that 178,000 people were living with HIV in the country, among which some 14,000 children below the age of 15 (MoHSS, 2008). According to National HIV Sentinel Survey (NHSS, 2014) the overall HIV prevalence of 16.9% in 2014 signified a small decline from 18.2% in 2012. The United States Agency for International Development (USAID, 2004) report also argues that poverty, unemployment and HIV/AIDS remain the main causative factors towards hunger and starvation in the country. The USAID report also reported that the high prevalence rates of HIV in urban areas or towns and regions with a significantly high population number and high dependency on rain-fed agriculture, the way it is managed very important towards food security in the country, especially when it comes to HIV/AIDS which is known to have an intense effect on the food production and marketing in the country. FAO (2009) also argues that in spite of Namibia being classified as an upper-middle income country, a GINI coefficient of 0.58 makes income distribution in the country to be one of the most unequal civilizations in the world.

FAO (2015) reported that women make up more than half of the labour required to produce the food consumed in sub-Saharan African countries and perhaps 75% of the labour for food in developing countries. According to the Vulnerability Assessment Committee (VAC, 2011) in Namibia the crop production sector is about 60 to 80% controlled by women, while men dedicate the majority of their time primarily looking after their livestock, or moving to towns in urban areas in looking for jobs. FAO, (2013b) reported that Namibia is among the seven African countries that have not accomplished their post-2015 sustainable development goals in terms of food security with 42.3% of the Namibian population reported to be malnourished. FAO (2015) also reported that the eradication of the persistent malnutrition by the year 2030 is an important component of the suggested Sustainable Development Goal 2 of the new post-

2015 agenda to be implemented by the numerous unindustrialized countries. It is also national knowledge that even his Excellency the President of the Republic of Namibia, Dr Hage Geingob, has declared war on poverty. However, cereal production over the past decade has decreased relentlessly due to climate change and wide spread period of dry weather conditions. VAC (2011) reported that the climate change which led to a decline in cereal food production and poor livestock conditions triggered an increase in the number of people in need of food assistance in 2015/16.

In the smallholder farming sector in rural Namibia, the soil quality is affected by soil erosion and the leaching of plant nutrients due to the exhaustive conventional soil preparation practices that leave the soil structure detached, increasing organic matter mineralization and resulting in poor soil structure (FAO, 2002). FAO (2009) assertions that poor crop rotations, deforestation and removal or burning of crop residues results in insufficient vegetation cover which leads to unsuitable reparation of organic matter or soil plant nutrients. In addition, tillage has always been used in agricultural production but has been proven to be harmful to the land due to the continuous turning over of the soil when using a mould-board plough (Givens *et al.*, 2009). Moreover, when the land is ploughed, the soil is disturbed, inverted and broken up burying crop residues leaving the soil bare and susceptible to soil erosion. The continuous ploughing creates plough pans which impede good root development leading to a decline in yields (Shetto, 1999). Furthermore, smallholder farmers face quite a lot of challenges when it comes to mineral fertilizer consumption which is normally low due to the high unaffordable prices of synthetic fertilizers (Mashavave, 2003). Hence, there is a need to focus on justifiable crop production practices that aim at improving crop production techniques, while at the same time improving soil fertility and also improving the environmental protection (Mazvimavi, K., Nyathi, P., Murendo, C, 2011). One of the suggested possibility to these unfavorable practices is conservation agriculture (CA) (Kuvare *et al.*, 2008).

## **2.2 Conservation Agriculture (CA) –Origin, definition and principles**

### **2.2.1 Definition and principles of CA**

Reicosky (2015) states that the first use of the term “conservation agriculture” (CA) originated from a Latin American Network for Conservation Agriculture Tillage meeting that was held in Morelia, Michoacán, Mexico, in 1997. Since then, CA has become a universal term that includes a package of farming techniques that broadly enhance the agricultural production by improving the soil fertility, while at the same time conserving the soil moisture, decreasing erosion, and aiming at the solicitations of soil enhancements.

FAO (2014) claims that, CA aims to conserve, improve and make use of natural resources more efficiently through interconnected management of the available soil, water and biological means combined with external inputs. It contributes to environmental conservation as well as to better-quality and sustained agricultural production. CA is defined as a system involving minimum or no mechanical soil disturbance, permanent soil cover, and cover crop diversification (FAO, 2014). CA is defined as an integrated system concept based on three key pillars: Continuous mulch retention on the soil surface; continuous minimum soil disturbance (zero or no-tillage); and diverse crop rotations and cover crop mixes (Kassam & Friedrich, 2009; FAO, 2009; Friedrich *et al.*, 2012). Conservation agriculture is only effective when used as a full package paying attention to the application of all principles rather than implementing only one of the principles and by good timing of all procedures (ZCATF, 2009).

#### **2.2.1.1 Minimum soil disturbance**

The minimum tillage system technique should not to be confused with other forms of Conservation agriculture Tillage systems that disturb the soil surface slightly. In CA, the area that is disturbed should not be wider than 15 cm or 25 % of the cropping area (ZCATF, 2009). Crops are planted by opening slight bands only to achieve proper seed

coverage is used (FAO, 2013a). Tillage methods such as ripping, direct planting and basin planting are used to achieve minimum soil disruption.

#### **2.2.1.1.1 Ripping**

Ripping is done using a ripper, which is a chisel-shaped animal- or tractor- drawn appliance. A ripper opens thin furrows that are about 5-10 cm deep. A ripper is a modern plough but with a tine attached to it instead of a mouldboard and does not turn the soil over like the mouldboard plough (Sims *et al.*, 2012). Ripping is done usually when the soil is dry and sowing of seed can be done either by hand or by a planter attached to the appliance (FAO, 2012c). Examples of rippers that are available on the market are the Baufi and the Magoye ripper.



Source: (FAO, 2014)

Figure 2: Baufi ripper



Figure 3: Magoye ripper

Source: (FAO, 2014)

#### **2.2.1.1.2 Direct planting**

Direct planting can be done using different equipment's which include the jab-planter, Li seeder and animal- and tractor- drawn direct seeders (e.g. Fitarelli direct seeders). A jab-planter is a hand operated instrument, designed in Brazil with two sections. The compartments hold fertilizer and seed and are both mounted on a wooden frame. The jab-planter has two tips that are cut at angles to allow it to cut into the soil when planting (Aikins, S.H.M., Bart-Plange, A., Opoku-Baffour, S, 2010). When pushed into the soil, the jab-planter creates a hole enough to accommodate seed and fertilizer. The jab-planter is opened by pulling the handle sideways to drop the seed and fertilizer through the two tips at the same time, and lifted again to cover the seed hence attaining minimum soil disruption (Ngwira, A.R., Thierfelder, C., Lambert, D.M, 2012). A Li seeder is a Chinese established hand hoe shaped instrument with two tips, the fertilizer and seed outlets. A Li seeder has a hollow handle to hold seed and a bag to hold fertilizer attached to the fertilizer outlet by a feeding pipe. The Li seeder has a pendulum bob that opens the seed and fertilizer tips when the seeder is pushed into the soil (FAO,

2013b). The Happy seeder and the Turbo seeder are tractor-drawn seeders that can be used to achieve minimum soil disturbance in conditions where there is loose or unfastened crop residues (Jatet *et al.*, 2010).

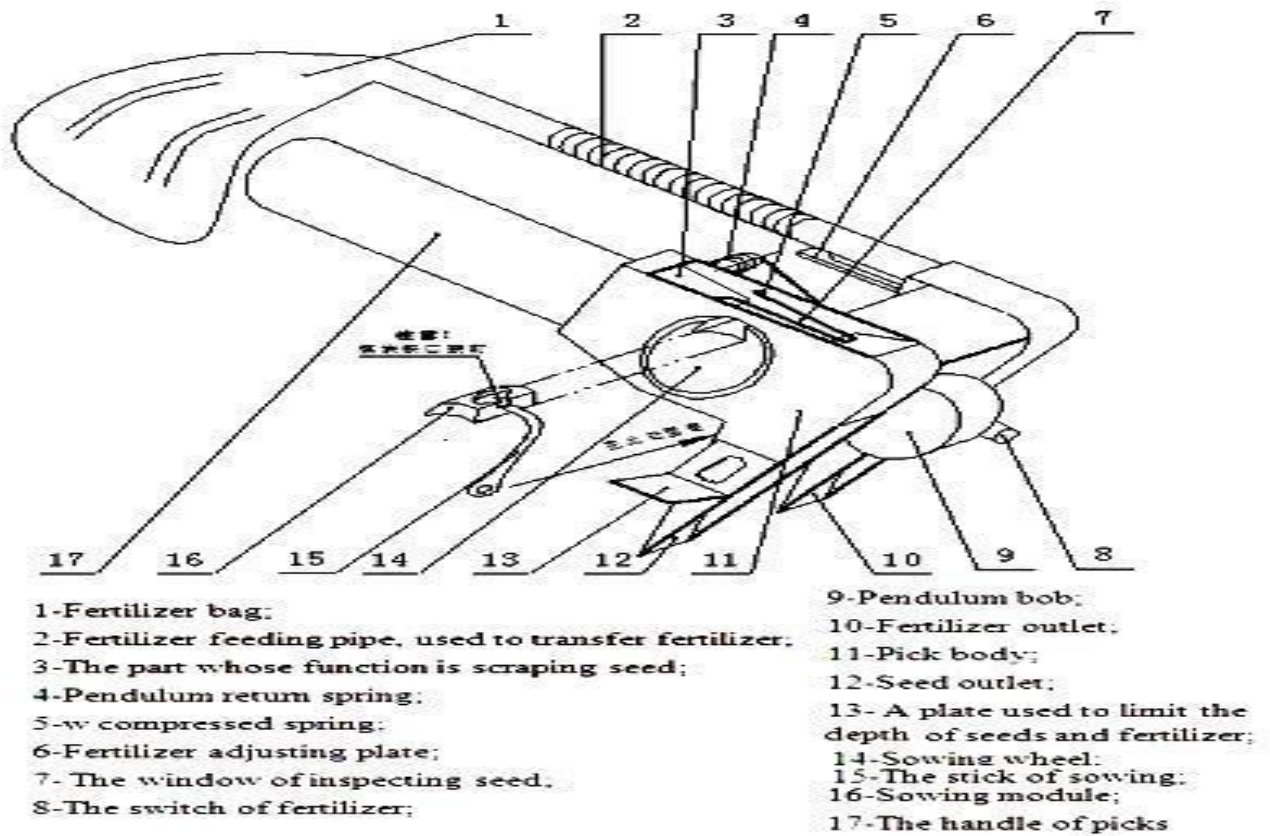


Figure 4: The Li seeder®.

Source: (FAO, 2013b).

### 2.2.1.1.3 Planting basins

Planting basins can be prepared using a hand hoe (Nyanga, P.H., Johnsen, F.H. akon, Kalinda, T.H., 2012, 2012). The preparation of planting basins is done by digging holes of the size enough to only hold the seed and fertilizer. Planting basins can be used for many crops including pearl millet, maize (*Zea mays* L.), groundnuts (*Arachis hypogaea* L.), and sorghum (*Sorghum bicolor* L.) Moench etc. (Twomlow *et al.*, 2008). Row and station spacing of basins and their depth are important features and they depend on the

crop being grown. Basins should be done on the same lines each season so it is important to do them correctly the first time they are done (ZCATF, 2009). Planting stations can also be prepared using a simple dibble stick to seed into the uninterrupted soil (Campbell, 1990).

### **2.2.1.2 Permanent soil cover**

One of the main pillars of CA is the ability to maintain permanent soil cover. This can be achieved by the retaining of crop residues, use of cover crops and practice of agroforestry (Abrol, I.P., Gupta, R.K., Malik, R.K, 2005). The organic soil cover can be categorized in to three categories of ground cover which are 30-60 %, > 60-90 % and > 90 %; and CA requires soil cover of more than 30 % this is measured soon after direct planting (FAO, 2013a). In cases where crop biomass is insufficient to provide a 30 % soil cover or more, grass or leaves can be imported into the field for residue retention (Mazvimavi *et al.*, 2011). To achieve improved soil cover there is a need to categorize crops that have high biomass production abilities and produce residue that has a high carbon-to-nitrogen ratio that decompose slowly in the field and select a crop system that retains the residue cover e.g. use of winter cover crops (Mc Carthy, J.R., P fost, D.L., Currence, D.H, 1993).

### **2.2.1.3 Diversification of crop rotations and plant associations**

The rotations of crops and plant relations are an important part of CA for the full benefits of CA system to be appreciated. Cover crop rotations and plant associations in pearl millet and maize-based systems are preferably with legumes (e.g. *Crotalaria ochroleuca* G.) which have the potential to add nitrogen into the system due to their biological nitrogen fixation (BNF) ability (FAO, 2010). For small scale farmers, grain legumes like cowpea (*Vigna unguiculata* (L.)) and pigeon pea (*Cajanus cajan* L.) are mostly favored because, in addition to their nitrogen influence, they also assist to food security to the resource constrained smallholder farmers (Thierfelder *et al.*, 2012). There is a need to intercrop in order to reduce competition and avoid the build-up of pests between the associate crops. An example of an intercropping system planned to reduce

competition is a system called “MBILI”. This system is mainly practiced mainly in Kenya (Woomer *et al.*, 2004). In this system, every other maize row is staggered by 25 cm and the maize and legume are planted as combined rows resulting in reduced competition but the same expected plant populations. A system called relay cropping may also be practiced to reduce competition between the associate crops. In this system another crop is added into the system when the leading crop is about to die or when it has reached a stage that will not lead to competition between the crops hence yield is improved in the end (Jones *et al.*, 2010).

### **2.3 Benefits of CA**

CA has been proven to increase crop yields while at the same time conserving the soil and water at a cheap operation costs in many different agro ecological zones (FAO, 2001). In addition, CA has been revealed to be useful in the production of different crops including pearl millet, maize, groundnuts, sunflower, potato etc. Minimal tillage has the prospects of eliminating the on-farm and off-site effects of tillage which are organic matter loss, compaction, soil erosion etc. (Dumanski *et al.*, 2006).

One of the main emphasis is the promotion of the disturbance of soil only where seed and fertilizer will be planted. Minimum soil disruption promotes many benefits to both the farmer and the environment. The disturbance of the soil surface is reduced, therefore leading to reduced wind, water erosion and reduced disruption of the soil micro fauna that are involved in mineralization of organic matter (ZCATF, 2009). Minimum soil disturbance is less energy intensive compared to conventional tillage and hence more affordable to the smallholder farmer (Shetto, 1999). A research study that was done in Brazil revealed that minimum tillage with tractors can save an estimated 6.4 litter/ha of diesel oil and a total energy budget decrease of 25 litter/ha of diesel oil the same per hectare (Fernandez *et al.*, 2008). At small scale farmer level, minimum soil disturbance has been reported to eliminate fees for hiring ploughs (FAO, 2012c). In southern Africa where the HIV/AIDS epidemic is upsetting the agricultural industry, CA is imperative since it decreases labour requirements (FAO, 2012d).

The maintenance of crop residue onto field structures has been reported to improve some soil physical and chemical characteristics (Ferreroa *et al.*, 2005). The application of crop residue as soil cover generates a conducive environment for soil macro- and micro fauna activity with the macro fauna group creating pores that improve the air circulation, root growth and water permeability (Mutema *et al.*, 2013; Anderson, 1988). Soil macro fauna play a significant role in the improvement of the soil structure and minimum tillage and retention of mulching materials have been proven to advance the large quantity and improve higher species richness of these soil macro fauna (Mutema *et al.*, 2013). Thierfelder and Wall, (2010) suggested that CA can improve the soil quality by improving the infiltration rate hence moisture content compared to conventional farming. Soil macro fauna, comprehensive stability and soil total carbon was shown to be higher in CA plots compared to conventionally ploughed plots in a long-term experimental trial (Thierfelder & Wall, 2010).

## **2.4 Challenges of CA and Impact on Adoption Rates**

### **2.4.1 Weed definition**

What makes up a weed is basically a matter of opinion. Ralph Waldo Emerson defines weeds as “plant[s] whose indispensable value have not yet been revealed” (Harlan & DeWet (2007)), while others, such as L. H. Bailey & Bailey (1941), appealed that any plant growing where it was not wanted makes up a weed. There appears to be no worldwide definition of a weed, and the definition most of the time changes in response to cultural values (Arcioni, 2004). For the significance of this study, a weed is defined as a plant which competes with a planted crop for water, light, and nutrients (Weed Science Society of America, 2016).

#### **2.4.1.1 Weed dynamics in CA systems**

Even though CA provides a number of benefits to both small scale and large scale farmers’, this include the improvement of the soil water holding capacity (Mupangwa, Twomlow, & Walker, 2008; Thierfelder & Wall, 2009), reduction in the pest and disease occurrence (Kassam, Friedrich, Shaxson, & Pretty, 2009) and a better-quality soil structure (Thierfelder & Wall, 2010), However, the system does not come without

its challenges. Subsequent to that, ploughing usually acts as the first weeding for many farmers practicing Conventional Tillage (CT). However, farmers practicing CA most of the time experience an increase in the weed pressure (Chauhan et al., 2012; Vogel, 1994).

The influence of tillage on weed smothering nevertheless, not clear-cut. As different studies argue differently, some studies have established that tillage brings weed seeds up to the soil surface, where they are more voluntarily exposed to sufficient light and moisture conditions which is needed for germination (Teasdale, 1998). Dissimilarly, other research studies have concluded that because conventional tillage systems may bury weed seeds, weed pressure intensifies in no-till agricultural systems due to seeds being left on or near the soil surface (Mavunganidze, Madakadze, Nyamangara, & Mafongoya, 2014). In addition to tillage burying weed seeds, farmers may also find it easier to hand hoe weed on ridges created by tillage (either manual or mechanical) than on flat, un-tilled land, and are, therefore, more likely to weed more comprehensively. Hence, the effects of tillage on weed dynamics may seem to be largely reliant on factors such as site physical characteristics, weed populations or dynamics, and different crop management strategies, including crop diversification and the use of green manure cover crops (Lee & Thierfelder, 2017).

The negative impact of weeds on crop growth, development, and yield is well-documented and subsequently, weed control is of particular importance for farmers practicing CA (Christoffoleti *et al.*, 2008; Mafongoya *et al.*, 2016; Mashingaidze, Madakadze, Twomlow, Nyamangara, & Hove, 2012; Nyamangara *et al.*, 2013). As a consequence, a number of large scale CA systems in the Americas and Australia rely on herbicides for weed control (Christoffoleti *et al.*, 2008; D'Emden, Llewellyn, & Burton, 2008). While the success of CA in large-scale farming enterprises can be partly, attributed to herbicide use, the fears regarding the short- and long-term environmental effects of herbicide application, including herbicide resistance (Kirkegaard *et al.*, 2014; Norsworthy *et al.*, 2012), the presence of herbicides and their metabolites in waterbodies (Kolpin, Thurman, & Linhart, 1998), and their influence on soil microbes (Duah-Yentumi & Johnson, 1986) have been raised up. A recent study has also found a

correlation between prominent glyphosate levels in pregnant women and shorter gestational periods (Parvez *et al.*, 2018). In addition, the efficiency of herbicides in some CA systems has also been interrogated and examined. The efficiency of herbicide may be reduced in CA systems because surface-applied herbicides are not integrated into the soil (Chauhan *et al.*, 2012) and cover or cereal crop residues retained as mulch can act as a barrier between the herbicide and its projected target (Liebl, Simmons, Wax, & Stoller, 1992).

In poor resource constrained smallholder CA systems, where farmers rely more often on mechanical, rather than chemical control due to financial limitations, greater than before weed pressure can be predominantly challenging (Muzari, Gatsi, & Muvhunzi, 2012; Nyanga, Johnsen, & Kalinda, 2012). In Zimbabwe, planting basin-based CA systems needed to be weeded an average of 2.5 and 2.6 extra times after seeding during two growing seasons, while conventional tillage systems required weeding 1.8 and 2.0 times during the same period (Nyamangara *et al.*, 2013). Equally so, weeding in the CA systems essentially required an average 41.5 person days per ha, while weeding in the conventional systems took an average of 24.8 person days per ha (Ibid.). In Zambia, labor burdens were described to have increased from 27 person days per ha for conventional tillage to 35 days under ripper tillage, 58 days using hand hoe tillage, and 81 days under the planting basin method (Haggblade & Tembo, 2003). Furthermore, to economic significances, increased labor burdens devour a number of social consequences as the weeding activities become an affliction to women and children in SSA (Nyamangara *et al.*, 2013).

#### **2.4.1.2 Predominant weed species of northern Namibia**

There a number of weed species that are prevailing in northern Namibia are they are common throughout SSA [e.g., *Boerhavia diffusa* L. (spreading hogweed), *Commelina spp.* L. (including *Commelina benghalensis* L, also identified as (Benghal dayflower), and *Cynodondactylon (L.)*(Couch grass)]. Whereas others, namely *Acanthosicyosnaudianus* (Sond.) C. Jeffrey (Gemsbok cucumber) and *Cleome gynandra* L. (African cabbage), appear primarily in southern Africa (Lee & Thierfelder, 2017). In the northern of Namibia, some weed species have numerous uses and are kept on the

field to be harvested as leafy vegetables [e.g., *C. gynandra* and *Corchorustridens L.*, commonly known as wild jute (Roodt, 1998a)] or for medical purposes (e.g., *Harpa gophytumzeyheri D.*, generally well-known as devil's claw).

Other or some of the weed species merely serve as irritation, or, in the case of *C. dactylon* and *Alectravogelii .B.* (yellow witch weed), are liable for large yield losses (Mangosho & Mupangwa, 2013). A number of grass species are common in agricultural fields of northern Namibia, as well as the annual species *Urochloa brachyura* (Hack.) Stapf, *Tragus berteronianus* Schult, and *Dactylocteniu maegyptium (L.) Willd.*, though perennial species include *C. dactylon*, *Cenchrusciliaris L.*, and *Pogonarthrias quarrosa* (Roem. & Schult.) Pilg (Mueller, 2007). These weeds, in the midst of others, often cause substantial yield decreases in CA systems in northern Namibia. Subsequently, farmers seek use manual, mechanical, chemical, cultural, and biological weed control methods to decrease weed pressure (Lee & Thierfelder, 2017).

#### **2.4.1.3 Weed density**

Weed density can be well-defined as the number of weeds within a certain area (generally m<sup>2</sup>). Weed density is every so often measured by using a quadrat to demarcate a demonstrative area where weeds will be counted (Barbour *et al.*, 2008). While numerous approaches for determining quadrat size and number of quadrats per area exist, the general endorsement is to make sure that quadrat size is large enough to accommodate the most regularly-occurring weed species in 63-86% of all quadrats (Barbour, 2008). Furthermore, quadrat sizes of less than 1 x 1 m are deliberated preferable in meadow or grassland systems, where weed species are not spread far apart (Bonham, 2003). Plants that are embedded within the quadrat are counted, while plants that are not embedded within the quadrat but whose canopies occupy the quadrat are not included in the count (Barbour *et al.*, 2009). The recommended number of quadrats to be used differs and is largely reliant on time and resources (Barbour *et al.*, 2008; Bonham, 2003). A number of studies weed populations in arable settings have used 1 x 1 m quadrats six times within a farmer's field (Chivinge, 2000), while other studies used two 0.5 x 0.5 m quadrats in 8 x 6 m plots (Mashingaidze *et al.*, 2012) and 5.4 x 6 m plots (Mhlanga *et al.*, 2016) or one 1 x 1 m quadrat in 4 x 5 m plots (Mwangi, Kihurani,

Wesonga, Ariga, & Kanampiu, 2015). Although accuracy and precision increase with a larger number of quadrats, these studies pointed toward the range for adequate quadrat numbers varies, provided measuring methodologies are reliable.

#### **2.4.1.4 Weed biomass**

The weed biomass is a commonly-used quantity for determining weed pressure as it can serve as an indicator for resources (such as water and light) taken up by non-crop species (Bonham, 2003). Characteristically, only aboveground biomass is measured when conducting weed surveys due to the backbreaking nature of uprooting weeds to measure belowground biomass (Barbour *et al.*, 1999). Since, fresh weed biomass weights are extremely inconstant, dependent on the moisture prominence of not only the plant, but the soil and atmosphere as well, dry weights (from oven or air drying) are commonly measured to be more dependable indicators of plant biomass (Bonham, 2003).

#### **2.4.1.5 Weed species richness, diversity, and evenness**

Though the expressions are often used interchangeably, weed species richness and diversity refer to two distinct conceptions. Although weed species richness discusses the number of different weed species in a given area, weed species diversity refers to the number of individual plants signifying each species within a given area (Spellerberg & Fedor, 2003). Weed species diversity and evenness have often been calculated using the Shannon-Weiner index in studies on weed control and weed dynamics (Mhlanga *et al.*, 2015; Mtambanengwe *et al.*, 2015; Muoni, Rusinamhodzi, Rugare, *et al.*, 2014; Murphy, Clements, Belaoussoff, Kevan, & Swanton, 2006). In the Shannon-Wiener diversity index, a higher number specifies higher weed diversity. Weed species evenness refers to how similarly the weeds are disseminated across an area; this number ranges between 0 and 1, with 0 demonstrating no species evenness (i.e. only one specie present) and 1 demonstrating that all species are disseminated similarly across the plot (Muoni *et al.*, 2013).

#### **2.4.1.6 Weed management**

Weed control is one of the major restrictions in the adoption of CA by smallholder farmers. Farmers customarily till their land to regulate weeds (Wall, 2007) and so a change from the customary conventional practices to CA results in a change in weed flora dynamics (Gianessi, 2009). HENCE, this calls for a comprehensive understanding of the developing weed species and their control of which most farmers lack this, hence generating a challenge in weed control (Derpsch & Friedrich, 2008). The dynamics of weeds has been described to intensify under CA due to a buildup of weed seeds in the top soil where there are conditions that indulge germination for some weed species (Spandl *et al.*, 1999).

Throughout the preliminary stages of CA adoption, successful weed control is commonly costly and problematic but over time, with the use of herbicides and residue cover, there will be a drop in the population of weeds (Wall, 2007; Muoni *et al.*, 2013). Nevertheless, herbicide use is expensive to the resource poor smallholder farmers (Gowing & Palmer, 2007) who will, in the end, alternate to the use of hand hoeing as the central weed control means (Mashingaidze, 2004). The retention of crop residues as ground cover, which is one of the three principles of CA, has been established to hinder smooth hoeing resulting in more time taken in the control of weeds (Vogel, 1994). Hence there is a need to understand weed ecology that could reduce the amount of herbicide used in CA to a level that does not surpass those used in conventional tillage (Nakamoto *et al.*, 2006). A change from conventional to minimum tillage farming results in a change in the community of decomposers in the soil and as shown by Altieri (1999), fungi tend to dictate more than bacteria and this restricts the use of herbicides since they destroy fungi more than bacteria yet herbicides are an option in the control of weeds in CA.

### **2.4.2 Residue retention**

Small scale food production is primarily supported by mixed crop-livestock systems (Herrero *et al.*, 2010). Now in these mixed crop-livestock systems the usage of crop residues as cattle feed create a major struggle on the residues being left in the field as soil mulch and being feed to cattle (Dubreil, 2011). These antagonisms for residues will in-turn put forth a competitive pressure on the use of residues as mulch. In Eastern and Southern Africa, smallholders usually use crop residues to feed cattle during the dry season and the problem of residue trade-offs is high in areas where farmers encounter long dry spells between dry seasons with limited cattle feed substitutes (Jaleta *et al.*, 2012). Some smallholder households use crop residues as a source of firewood thereby leaving less than enough residues for soil mulch. Now in some areas, crop residues are utilized as building material in construction of fence walls and storage assemblies hence aggregating competition for residue use (Jaleta *et al.*, 2012). Crop residues also create problems in land preparation by raking and obstructing planting equipment and make hoe weeding more problematic so some households burn the residues to improve this problem. Some households burn crop residues to reduce the build-up of pest and rodent populations around their homesteads and fields (Erenstein, 2003). In addition, the amount of crop residues used as mulch is subject to the distance of the plots from the homestead. In plots that are closer to the homestead, it is easier for the farmer to take away the residues for cattle feed and other uses while if the distance is elongated it becomes backbreaking so the farmers incline to leave the crop residues in the plots for residue retention (Jaleta *et al.*, 2012).

### **2.4.3 Nitrogen management**

Indeed, the managing of nutrients in CA systems is biological-based. Many biotic and abiotic mechanisms of the system play an important role in the nutrient outcome of the system therefore it is not a simple input-output model but a complex model (Kassam & Friedrich, 2009). All practices that are carried out under CA should aim at protecting the soil biota involved in breakdown of residues to release nitrogen (Habte, 2006). Nitrogen release from different cover crop residue is determined by on the quality of residue and therefore the nitrogen may be less available to crops during the season (Schomberg *et*

*al.*, 1994). Plant available soil-nitrogen is a calculated share of nitrogen accessible to plants within a season after the solicitation of nitrogen from different sources (Sullivan *et al.*, 2011). There is a need for smallholder farmers to comprehend all these developments involved in nitrogen availability by crops for improved crop production.

## **2.5 The potential use of GMCCs as Weed and Nitrogen management tools**

A cover crop is a living ground cover crop that may be intercropped, rotated with the main crop or introduced into a cropping systems when the main crop is about to die and normally killed before introducing the subsequent crop (Hartwig & Ammon, 2002). Cover crops might be annual or perennial and in the case of being perennials, they may be preserved into the next season without replanting. Cover crops may be also legumes or non-legumes. Leguminous cover crops are most desired since there is less nutrient competition in comparison to non-legumes (Mapfumo *et al.*, 2001).

Cover crops may be introduced into pearl millet the pearl millet- based or maize systems either by rotating them with the pearl millet/maize or by relay cropping them when the pearl millet/maize is about to die in order to improve the soil and environmental quality (Mapfumo *et al.*, 2001). Different leguminous cover crops, depending on their quality, provide different benefits and there is no individual cover crop that will give all the specific benefits (Kladviko, 2011) so there is a need to identify a particular cover crop for a specific given role (Samba *et al.*, 2002).

Cover crops have been shown to have a smothering effect on weeds leading to reduced weed populations. Some leguminous cover crops such as black sunnhemp have an allelopathic effects on a certain number of weed species such as the smooth pigweed (*Amaranthus hybridus L.*) (Skinner *et al.*, 2012). The different leguminous cover crops compete for essential growth elements such as light, water and nutrients with weeds and eventually leading to their reduction in numbers (Hartwig & Ammon, 2002).

It is known that rotations with different green manure cover crops have been shown to increase the weed species diversity due to decline in the numbers of dominant weed species thus avoiding the dominance of certain weed species (Brainard *et al.*, 2008). In the case of leguminous, involving cover crops integrated into a cropping systems may

add nitrogen to the system in the process increasing the fertilization costs (Kladviko, 2011). Leguminous cover crops helps to fix nitrogen and this nitrogen may possibly benefit the succeeding crops in the following season (FAO, 2010).

## **2.6 Characteristics of the possible GMCCs used under CA**

*Tephrosia vogelii* (Hook. f.) also known as the Fish bean or Fish-poison bean, is an African leguminous tree. Fish bean has a high tolerance of acidic poor soils and can grow well in areas that receive annual rainfall of 850-2650 mm and the legume can tolerate temperatures between 12-27°C (PACE, 2011). However, Fish bean is not edible to animals and it is capable of accruing considerable biomass which is an improvement for its use as ground cover under CA (Rutunga *et al.*, 1999). Rutunga *et al.*, (1999) discovered that fish bean may possibly fix up to 154 kg nitrogen ha<sup>-1</sup> and is able to produce a total biomass of 9000 kg ha<sup>-1</sup> over a period of six months. In addition, fish bean is affected by a substantial amount of disease and pests that affect tomatoes, tobacco etc. hence the crop should not be relayed or rotated with such crops (PACE, 2011).

### **2.6.2 *Crotalaria* species**

*C. juncea* L. also known as the Black sunnhemp or Brown hemp is increasing fast growing legume crop that is herbaceous and annual and is capable of growing up to length 3m tall (USDA-NRCS, 2012). Sunnhemp contains a number toxic alkaloids in the seed and pods but it is used as fodder to nourish goats and cattle. Sunnhemp can yield up to 5700 kg dry matter ha<sup>-1</sup> and it is proficient for fixing up to 136 kg nitrogen ha<sup>-1</sup> and its seed contains about 34.6 % crude protein (Duke, 1983; Clark, 2007). Sunnhemp is responsible for the smothering of both weeds and crops through the production of allelochemicals so it should be rotated or intercropped with crops tolerant to its allelochemicals (Skinner *et al.*, 2012). It was also recently reported the above mentioned cover crop has nematicidal properties and is capable of smothering of certain species of nematodes (Clark, 2007). Sunnhemp is confronted with a number of fungi (up to 38 species e.g. *Fusarium undum*), a number of bacteria species (up to 6 e.g.

*Pseudomonas cyamopsicola*) and many viruses (up to 10 e.g. Alfalfa mosaic virus) and the black beetle is the most common pest to the crop (Duke, 1983).

In addition, *C. ochroleuca* which is also known as Red sunnhemp or Slenderleaf rattlebox is a herbaceous legume which is inherently from Africa (Pohill, 1982). This cover crop is an erect annual with 3-foliolate leaves and the crop can grow up to 2.5m (Hyde *et al.*, 2013). In a study done by Samba *et al.*, (2002) indicated that slender leaf rattlebox can fix an amount of up to 83 kg nitrogen ha<sup>-1</sup> and its plant material contains about 74.5g protein per 100g plant material (Schippers, 2004). *C. grahamiana* which is commonly known as common rattle pod is a herbaceous perennial legume with 5-7 foliolate leaves and is capable of growing up to 2 m tall (Pohill, 1982). In a study carried out by Gathumbi *et al.*, (2002), it showed that bushy rattle pod is capable of fixing 142 kg nitrogenha<sup>-1</sup>.

### **2.6.3 *Mucuna pruriens* var. *Utilis* (L.) DC (Velvet bean)**

The leguminous cover crop known as velvet bean is a fast growing annual or perennial leguminous vine native to tropical regions that grows up to 18 m in length on the ground (Taylor & County, 2012). In addition, velvet bean is grown as a cover crop appreciated as an anti-erosion crop and also grown for its ability to fix nitrogen (Mureithi *et al.*, 2003). Velvet bean is a nutritious cover crop with green forage protein content of 15.1 % (Tan *et al.*, 2009). Okito *et al.*, (2004) found the BNF contribution of velvet bean to be around 60 kg of nitrogen ha<sup>-1</sup>.

### **2.6.4 *Vigna unguiculata* (L.) Walp. (Cowpea)**

The leguminous cover crop known as cowpea is an annual herbaceous plant and has twinning stems. The cover crop has a number of different cultivars that has different bushiness and erectness (Barnard, 1969). The cover crop can grow up to 80 cm and can get up to 2 m for the climbing cultivars (Légèreet *al.*, 2013a). The leguminous cover crop is able to fix up to 140 kg residual nitrogen ha<sup>-1</sup> in the soil when it is well nodulated (Mullen, 1999).

### **2.6.5 *Lablab purpureus* (L.) Sweet (Lablab)**

The cover crop known as lablab is a perennial climbing legume that can grow up to 2 m in length (Sheahan, 2012). When legume is well nodulated, lablab can fix up to 140 kg residual nitrogen ha<sup>-1</sup> into the soil (Muldoon, 1985). Furthermore, lablab seeds and pods contain roughly an estimate of 20–28 % protein (Naeem *et al.*, 2009). The legume can grow in a wide range of soil pH and can tolerate drought (Muldoon, 1985). The crop is proficient to producing biomass of up to 5 tons/ha and each ton of biomass producing 22 kg of nitrogen according to a study done by (Valenzuela & Smith, 2002).

### **2.6.6 *Canavalia ensiformis* (L.) DC (Jack bean)**

The leguminous cover crop known as jack bean is a perennial fibrous, herbaceous legume that is ordinarily used as a fodder cover crop and as an assistance in the human nutrition (FAO, 2014). The crop can grow up to 2 m high with 8-20 cm long trifoliolate leaves (Légère & Tran, 2013). Oliveira *et al.*, (1999) has indicated that jack bean has smothering effect on certain species of phyto-pathogenic fungi. Furthermore, in a study carried out by Kessler, (1990) in Mexico, jack bean reported to have yielded seed ranging from 1.0 to 3.8 t ha<sup>-1</sup> depending on the quality of rainfall that has been distributed over the seasons. In addition, Bonsu & Asibuo, (2013) have reported that the biomass production of jack bean was reported to be 5000 kgha<sup>-1</sup>.

### **2.6.7 *Raphanus sativus* (L.) (Fodder radish)**

According to FAO, (2013b) fodder radish is an annual cover crop that is in the brassicaceae family. The cover cop can grow up to 0.5 m in height. In addition, fodder radish is a non-legume that produces radishes that can weigh up to 27 kg. The cover crop is high in biomass yielding but it is susceptible to aphids that attack the brassicaceae family.

### **2.6.8 *Vigna subterranea* (L) (Bambara nut)**

The cover crop, known as *Vigna subterranea* (L.) Bambara nut is a native African legume, and it is reported to be the third most important legume on the African continent in terms of consumption and its socioeconomic impact at domestic level. The legume

trails behind *Arachis hypogaea* (A.) (Groundnut) and *Vigna unguiculata*(L.) Walp. (Cowpea). The legume is a nitrogen-fixing cover crop, and it is reported to fix as much as 184 kg nitrogenha<sup>-1</sup> according to a study done by (Légère *et al.*, 2013b). The legume produces a moderate biomass yield and it can be used in controlling weeds due to its vigorous growth or as dead mulch. Bambara nut is reported to contain about 3- 4 % nitrogen on dry matter basis (Undersander *et al.*, 2014). Bambara nut has a shallow root system and perform best in sandy soils or well-drained soils with a pH that ranges from 6.0-7.0 (Verhallen, 2001).

#### **2.6.9 9 *Arachis hypogaea* (A.) Groundnut**

The leguminous green manure cover crop which is commonly known as peanut, and also known as the groundnut (*Arachis hypogaea* (A.) is a legume cover crop grown which is mainly grown for its consumable seeds. The crop is normally grown in the tropics and subtropics regions, and it is of importance to both small scale and large scale commercial producers. Furthermore, the legume is classified as both a grain legume and also as an oil crop, due to its high oil content. Groundnut is an annual legume that grows well on well-ventilated soils. The legume can grow up to 300 cm in height and it is responsible for fixing nitrogen biologically (Undersander *et al.*, 2014).

#### **2.7 Rotations of GMCCs in Cropping Systems as a Residue Management Strategy**

Pearl millet and maize biomass yields are generally low in the small scale farming set up due to their low crop productivity. Hence, this creates a competition for the use of pearl millet and maize residues that have a multi-purpose benefit in the smallholder households (Dubreil, 2011). Pearl millet and maize residue can be retained in the field to give many benefits such as weed control, improving soil properties and assisting in the moisture retention hence improved yields (Mhlanga *et al.*, 2015b). However, depending on different communities, pearl millet and maize residues may be used for many other purposes such as cattle feed, source of fire and building material and, thus, generates competition for their use hence, calls for different strategies to increase biomass production to reduce competition of pearl millet and maize residues (Dubreil, 2011). In

addition, amongst the possible strategies is the incorporation of GMCCs into cropping systems as rotations to assist in the supplementary biomass production. Furthermore, rotations are cropping systems in which more than one crops are grown in succession on the same piece of land (FAO, 2010). Since most GMCCs have a high biomass production ability, their addition in the cropping systems as rotational crops combined with retention of the residue ensures additional biomass. Furthermore, yield benefits of rotating cover crops with pearl millet and maize have been well documented and their improvement to the two crops' productivity subsequent resulting in more biomass being produced hence reducing the antagonism for the use of the residues (Bonsu & Asibuo, 2013).

## **2.8 General overview of GMCC use in Pearl millet and Maize-based Cropping Systems**

Different GMCCs have been proven to improve crop productivity in pearl millet and maize-based systems in different parts of the world. Indeed, GMCCs have been shown to improve yields of the subsequent pearl millet and maize crop when grown in rotation (Blevins *et al.*, 1990). Yields of up to 60 % or more compared to pearl millet or maize monocropping have been recorded by Mhlanga et al 2015b. GMCCs have also has been shown to improve yields when grown as intercrops with maize in Mozambique (Rusinamhodzi *et al.*, 2012). Furthermore, Teasdale *et al.*, (2007) has substantiated his claim that GMCCs do have a suppressive effect on weeds and eventually reducing the need for use of herbicide. Equally important, the ability of GMCCs to fix nitrogen and to smother weeds reduces the costs of farm operation for resource-poor smallholder farmers. All in all, although the advantages of the GMCCs are known, the information is still scarce in Namibia and research work needs to be done to identify suitable GMCCs to be integrated in the smallholder farming set ups as rotations. This study presents results from two experiments in which GMCCs were grown as rotational crops with pearl millet in Mashare Irrigation Training Center (MITC), Kavango East region and maize at Liselo Research Station (LRS), Zambezi region, over two successive seasons.

## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

#### 3.1 Site description

The experiments were carried out at two sites; Mashare Irrigation Training Center (MITC) and Liselo Research Station (LRS). MITC (17.889300°S; 20.170258°E) is located in the Mashare Constituency (north of Rundu Town), Okavango East Region (Figure 5). The station is situated about 44 km from Rundu along the Trans-Kalahari highway. It is situated at an altitude of 1050 m above sea level and is characterized by *Chromic Luvisols* (FAO, 2009). The site receives an average annual rainfall of about 550-650 mm and daily temperatures can reach up to 33 °C.

LRS (17.52°S; 24.23°E) is situated about 7 km outside Katima Mulilo along the Trans-Kalahari highway. LRS has an altitude of 964 above sea level and the site is characterized by sandy soils (Clay 4 %, Silt 13 %, Sand 83 %) classified as moderately deep Arenosols and Luvisols formed on granitic rocks according to FAO classification (Vogel, 1994) with a clay content of less than 5 % (Nyagumbo, 1999). LRS receives an annual average rainfall of about 750-1000 mm and maximum daily temperatures that may reach up to 35 °C in summer. Both sites lie in Namibia's tropical savannah (Köppen & Geiger, 2000) and receive rainfall in a unimodal pattern (Vincent and Thomas, 1960).



### **3.2 General Study Descriptions**

The study comprises of two experiments set at MITC and LRS. In the first experiment (Experiment 1), Pearl millet (*Pennisetum glaucum*) was rotated with different GMCCs to evaluate their effects on the productivity (grain and biomass yields) of the succeeding pearl millet crop, weed populations, ground cover and supplementary biomass production. In the second experiment which was conducted at LRS, maize (*Zea mays*) was rotated with different GMCCs to evaluate the effects of the cover crops on the productivity of the succeeding maize crop, weed populations, ground cover and supplementary biomass production. All crops were grown under rain-fed conditions (Figure 5).

#### **3.2.1 Background of the Trial**

The experiment was initiated in the 2016/2017 summer growing season with GMCCs planted across all plots at both sites (location 1). In the following season (2017/2018), pearl millet and maize were planted across all plots where GMCCs were planted the previous season and another phase was developed where GMCCs were then planted (location 2). Thus, a two-phased rotation, where on one part of the trial was GMCCs and on the other part of the trial uniform pearl millet and maize. The cover crops and the uniform pearl millet and maize were rotated over seasons from then onwards. Thus, at each site, both phases of the rotation were planted each year (location 1 & 2). All treatments were seeded on their respective plots in all seasons. However, this study presents data from the two seasons of the experiment as seasons 1 (2016/2017) and 2 (2017/2018).

#### **3.2.1 Experimental Design**

The field trial was conducted at MITC and LRS as a Randomized Complete Block Design (RCBD) with the following ten treatments (alternating with uniform pearl millet at MITC and maize at LRS) blocked four times at each site see figure:

1a) Pearl millet (*Pennisetum glaucum*) (control): 75cm between rows, dribble seed and thin to one plant every 25cm (53,333 plants ha<sup>-1</sup> target population; 5 kg of seed ha<sup>-1</sup>).

- 1b) Maize (*Zea mays* L.) (Control) planted at 90 cm between rows and 25 cm between plants to achieve a plant population of 44444 plants ha<sup>-1</sup>.
- 2) Black sunnhemp (*Crotalaria juncea* L.) dribbled in rows 45 cm apart aiming an intra-row spacing of 5 cm (approximately 20 kg ha<sup>-1</sup> seed) to achieve a plant population of 444444 plants ha<sup>-1</sup>.
- 3) Pigeon pea (*Cajanus cajan* (L.) Millsp.) planted in rows 90 cm apart and 25 cm between plants (approximately 25 kg ha<sup>-1</sup> seed) to achieve a plant population of 44444 plants ha<sup>-1</sup>.
- 4) Cowpea (*Vigna unguiculata* (L.) Walp.) planted in rows 45 cm apart and 25 cm between plants (approximately 80kg ha<sup>-1</sup> seed) to achieve a plant population of 88888 plants ha<sup>-1</sup>.
- 5) Groundnuts (*Arachis hypogaea* (A.) planted in rows 45 cm between rows, 25 cm between plants, and one seed per planting station 44444 ha<sup>-1</sup>.
- 6) Velvet bean (*Mucunapruriens* (L.) DC) planted in rows 45 cm apart and 25 cm between plants (approximately 80 kg<sup>-1</sup> seed) to achieve a plant population of 88888 plants ha<sup>-1</sup>.
- 7) Lablab (*Lablab purpureus* (L.) Sweet) planted in rows 45 cm apart and 25 cm between plants (approximately 80 kg ha<sup>-1</sup> seed) to achieve a plant population of 88888 plants ha<sup>-1</sup>.
- 8) Bambara nut (*Vigna subterranean* (L) planted 45 cm between rows, 25 cm between plants, one seed per planting station 44444 plants ha<sup>-1</sup>.

9) Jack bean (*Canavalia ensiformis* (L.) DC.) planted in rows 45 cm apart and 25 cm between plants (approximately 80 kg ha<sup>-1</sup> seed) to achieve a plant population of 88888 plants ha<sup>-1</sup>.

10) Fodder cocktail: which comprise of (Fodder radish (*Raphanus sativus* L.), Red sun hemp (*Crotalaria ochroleuca* G. Don) & Velvet been (*Mucuna pruriens* (L.) DC)) dribbled in rows 45 cm apart aiming an intra-row spacing of 5 cm (approximately 20 kg ha<sup>-1</sup> seed) to achieve a plant population of 444444 plants ha<sup>-1</sup>.

A basal dressing fertilizer application of NPK (2:3:2) was applied at a rate of 150 kg ha<sup>-1</sup>, and 150 kg ha<sup>-1</sup> urea was applied as top-dressing to all maize and pearl millet treatments, that is treatment 1 in the first season and all treatments in the second season. The herbicides were used to control weeds at the onset of trial. Weed control was done manually by hand hoeing in all the plots, except the weed assessment quadrants, once the weeds were 10 cm tall or 10 cm in circumference for weeds with stoloniferous growth.

### **3.3 Field Measurements**

#### **3.3.1 Weed biomass and density**

Weed biomass and density were determined from 0.5-m × 0.5-m quadrats randomly placed three times in each plot. All weed species within the quadrats were counted and identified. Weed data was collected at 30, 60, and 90 days after planting pearl millet and maize (i.e., before each weeding). The quadrats were reduced in size to reduce errors in counting weeds in cases where too many weeds were found per unit area.

#### **3.3.2 Green Manure Cover Crop Biomass Yields**

The GMCC biomass yield for *Mucuna*, Lablab Sunnhemp and groundnuts was recorded from four central rows by 5 m (net plot) from each plot for GMCCs, except for Jack bean whose biomass yield was recorded from four central rows by 5 m (net plot). Bambara nut biomass yield was recorded from whole plot. Plant materials that were harvested from the net plot were weighed. Subsamples were collected, weighed and air-dried to constant weight then reweighed and used to calculate air-dried biomass yield

per hectare. Harvesting of the GMCCs was done whenever they reached their physiological maturity.

### **3.3.3 Pearl Millet, Maize and Biomass (Stover) Yields**

Pearl millet and Maize grain weights were recorded from 7 central rows by 5 m (whole plot) in each plot. The pearl millet heads were removed from the plant, and the dry matter content was determined for the stover. Subsample heads were randomly selected from each plot, because an error was made upon data collection, so we had to measure whole plot data and convert it to hectars and air-dried, shelled, and grain moisture content determined using a mini GAC moisture tester (DICKEY-John Corp.) and then reweighed. Pearl millet yield was calculated and then converted to mass per hectare.

## **3.4 Plot management**

Minimum tillage was done to all the plots. Planting of pearl millet, maize and legumes was done directly into rip lines in the second week of December for both seasons and the Rip lines were opened using a hand hoe at MITC and a Magoye ripper at LRS and planting was done by hand into the rip/ hoe lines.

### **3.4.1 Fertilizer application**

At both sites of the experiment, all pearl millet and maize crops received a basal fertilizer application in the form of Compound D (7 N:14 P<sub>2</sub>O<sub>5</sub>:7 K<sub>2</sub>O) at the rates of 7.0 kg N ha<sup>-1</sup>, 6.1 kg P ha<sup>-1</sup> and 5.8 kg K ha<sup>-1</sup> i.e. 100 kg ha<sup>-1</sup> Compound D. At LRS, the basal fertilizer was applied in the form of Compound D (7 N: 14 P<sub>2</sub>O<sub>5</sub>: 7 K<sub>2</sub>O) at the rates of 10.5 kg N ha<sup>-1</sup>, 9.2 kg P ha<sup>-1</sup> and 8.7 kg K ha<sup>-1</sup> i.e. is 150 kg ha<sup>-1</sup> Compound D i.e. 150 kg ha<sup>-1</sup>. Compound D was applied to pearl millet, maize and GMCCs at planting in both phases of the rotation. Pearl millet after pearl millet and maize after maize treatment only, in both phases of the rotation, further received top-dressing of urea at the rate of 150 kg ha<sup>-1</sup> AN split applied while the other treatments utilized nitrogen fixed by the previous cover crops.

### **3.4.2 Weed control**

All plots were treated with glyphosate [*N*-(phosphono-methyl) glycine] at a rate of 2.5 l ha<sup>-1</sup> (1.025 l ha<sup>-1</sup> active ingredient) at pearl millet and maize planting, followed by one hand weeding two weeks after planting. Afterwards, all plots were hand weeded whenever weeds reached 10 cm in height or length of species with stoloniferous-rhizomatous growth habit.

### **3.4.3 Residue management**

All residues from the previous season were retained in their respective plots.

## **3.5 Data collection**

### **3.5.1 Weed counts, biomass and species composition**

For weed density and biomass, a 50 cm × 50 cm quadrat was placed randomly twice in each plot before each weeding. The weeds within the quadrat were counted, subsequently cut at ground level and fresh weight recorded. The weeds were air dried for 168 hours to a constant weight and the biomass dry weight recorded. Weed species within the quadrat were identified using guidelines from Makanganise and Mabasa, (1999) and Botha, (2010), counted and recorded. All weeds not found in the guidelines and difficult to identify were classified as “other”. For perennial monocots, the stems were counted instead of the whole plant (Mashingaidze, 2012). Perennial grasses were taken across genus due to difficulties in identifying them at seedling stage. Weed species richness and the Shannon-Weiner diversity 30 and evenness indices were used to determine weed species diversity. The Shannon-Weiner diversity index (H') for each plot was calculated as follows (equation 1):

$$H' = (N \ln N - \sum (n \ln n)) / N, [1]$$

Where: H' is the species diversity through proportional abundance of species. Higher values of H' signify a greater diversity.

*N* is the total population density/m<sup>2</sup> and *n* is the weed species population of each weed species found within this location.

Evenness index was calculated as follows (equation 2):

$$E' = H' / \ln N, [2]$$

Where  $E'$  is the relationship between the observed number of species and the total number of species. Greater values of  $E'$  signify greater uniformity between species abundance. The  $E'$  value ranges between 0 and 1, with 0 indicating no species evenness (i.e. only one specie present) and 1 indicating that all species are distributed equally across the plot (Muoni *et al.*, 2013).

### **3.5.2 Plant available nitrogen (PAN) contribution by GMCCs**

PAN contribution of the cover crops was determined on an annual basis by collecting soil samples at the beginning of each season as follows: Before the introduction of treatments in October/November of each year, five samples were collected from each plot at 0-10cm; 10-20cm; 20-30cm, 30-60cm and 60-90cm depth. Each sample per plot comprised of at least 5 sub-samples. The samples were labeled with the following mandatory information: date, site, plot, treatment, replication and depth layer. The soil samples were analyzed for different parameter using the GIZ mobile soil laboratory to determine the amount of PAN in the soil.

### **3.5.3 GMCC grain and biomass yield**

For grain and biomass of GMCC, all the plant material from the net plot of 3.6 m by 5 m was harvested at maturity. In the treatments with the spreading type cover crops (e.g. velvet bean), plants were cut along the borders and along the center of the inter-row spaces instead of including the whole plants and the weight of the whole net plot recorded (biomass and pods were weighed separately). Sub-samples of approximately 1 kg of representative material (biomass and pods) were taken, weighed and then air-dried. The air-dry weights of the samples were recorded, the pods threshed, and grain moisture recorded using the Dickey-john® mini GAC® moisture tester. For the non-spreading type (e.g. pigeon pea), all plant material from each plot was harvested and weighed (biomass and pods were weighed separately).

#### **3.5.4 Pearl millet, maize grain and stover yield**

Pearl millet, maize grain and stover yield were recorded from the net plot of 3.6 m by 5 m (four central rows of pearl millet and maize, 5m long) in each plot. Head and cob sub-samples of 10 head and cobs, were selected at random, were taken from each net plot, weighed immediately, and then air-dried. The weights of the head and cob sub-samples after air-drying were recorded (to the nearest 0.1 gram), shelled and moisture content determined using a Dickey-john® mini GAC® moisture tester. Pearl millet and maize grain yields were converted to mass per hectare at 9 % moisture content and grain yield calculated. Pearl millet and maize stalks were cut into small pieces and sub-samples of approximately 500 g pearl mille and maize stover were taken from each plot. The pearl millet and maize stalks sub-samples were air-dried and the weight recorded (to the nearest 0.1 gram). Biomass content was determined for the stover and stover yield was calculated, by recording the stover wet dry mass and the dry out the stover sub-samples and then record the sample dry weight. The difference between the wet stover mass and the dry mass made up the total stover yield biomass.

#### **3.6 Statistical Analysis**

The data was subjected to analysis of variance (ANOVA) to test the effects seasons and GMCCs had on grain and biomass yields of pearl millet and maize, PAN contribution of GMCCs; and supplementary biomass quantity and weed composition using Statistix Version 9 statistical package for personal computers (Statistix, 2009). All weed density data were tested for normality and transformed using square root ( $x + 1$ ) before analysis to ensure homogeneity of variances where necessary (Gomez and Gomez, 1984). The interactions between sites, seasons and treatments were assessed using a linear mixed model where sites and treatments were treated as fixed factors and season as a random factor using GenStat 6th Edition statistical package for Windows (VSN International, 2002). Where the treatment means were significantly different, they were separated using the least significant differences (LSD) test at 0.05 probability level.

## CHAPTER FOUR

### 4.0 RESULTS

(Figure 6) shows that an amount of 499.9 mm rainfall was recorded at Liselo Research Station in the 2016/2017 cropping season, while an amount of 521 mm was recorded in the 2017/2018 cropping season. At Mashare Irrigation Training Center, 715.2 mm of rainfall was recorded in the 2016/2017 season while 530 mm rainfall was recorded in the 2017/2018 cropping season.

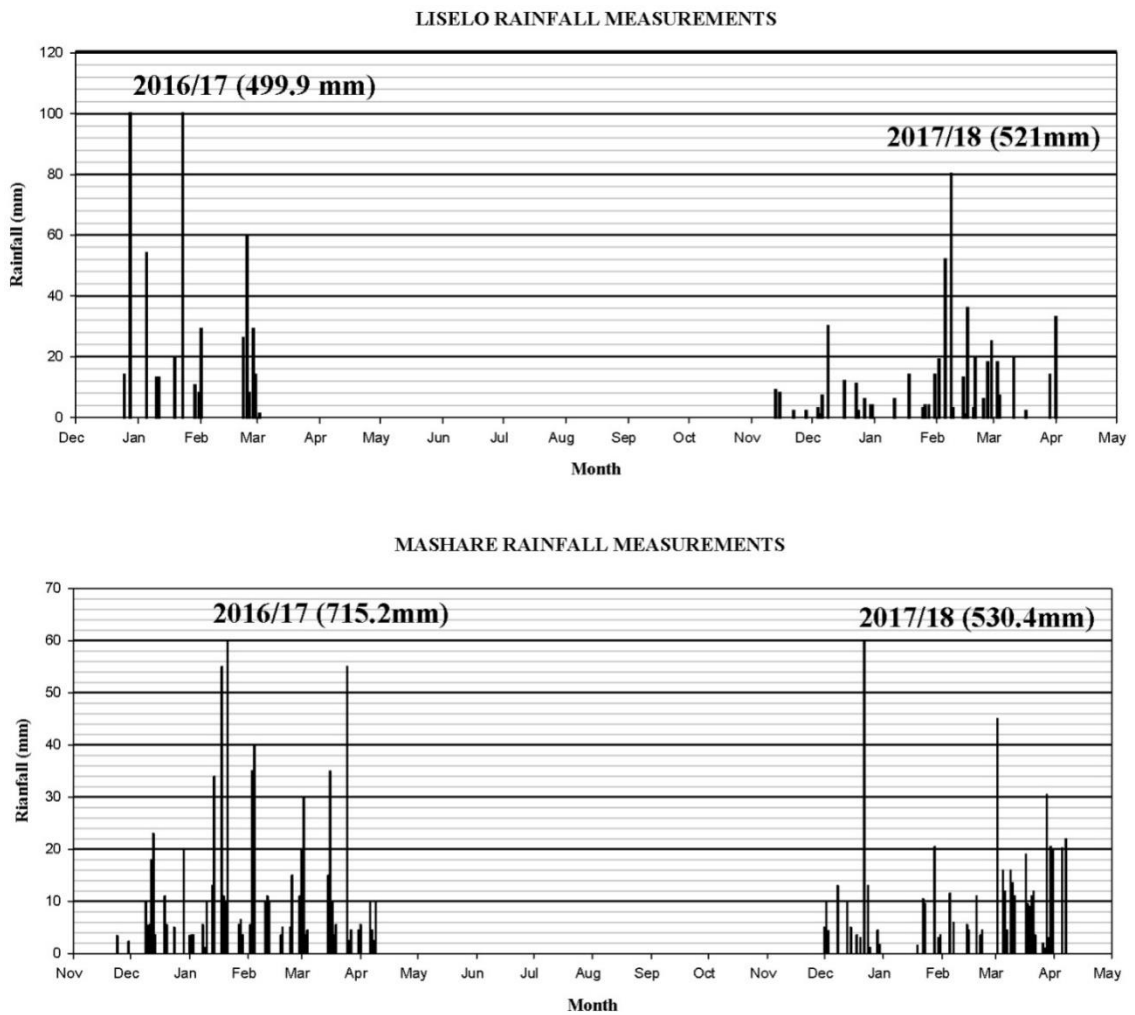


Figure 6: The amount rainfall recorded at MITC and LRS.

#### **4.1 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on total weed density, total weed biomass and weed composition.**

These results shown below are based on the 2016/2017-2017/2018 growing seasons at the two sites (MITC and LRS).

##### **4.1.1 Total weed density**

Weed density results were collected at approximately 30, 60, and 90 days after the seeding of GMCCs, pearl millet at MITC and maize at LRS in the second season.

The two sites, different pearl millet and maize-cover crop rotations and their interactions significantly affected total weed density across seasons at MITC and LRS as shown in the linear mixed model output ( $P < 0.05$ ) (Table 1). Different pearl millet-cover crop and maize-cover crop rotations significantly affected total weed density ( $P < 0.05$ ) in both seasons at MITC and LRS. Furthermore, at MITC, pearl millet-pigeon pea and pearl millet-groundnut rotation treatments had the highest total weed density (3500 weeds  $\text{ha}^{-1}$ ) and (3100 weeds  $\text{ha}^{-1}$ ), respectively (figure 6). Pearl millet-lablab rotation together with pearl millet-fodder cocktail and pearl millet-red sun hemp rotation treatments had relatively lower total weed densities of (1300 weeds  $\text{ha}^{-1}$ ), (1400 weeds  $\text{ha}^{-1}$ ) and (1500 weeds  $\text{ha}^{-1}$ ) respectively (Figure 6) in the first season.

There was a variable response in the number of weeds observed in the second season at the same site. There was a slight decrease in the pearl millet-fodder cocktail rotations and a higher decrease in the other treatments. The highest increase in total weed density of 54.7% was observed in the pearl millet-pigeon pea rotation treatment (i.e. from 3500 in 2016-2017 to 6400 weeds  $\text{ha}^{-1}$  in the 2017-2018 leading to this treatment having the most weed density in season 2 (Figure 7). The lowest increase of 61% was observed in the pearl millet-lablab treatment (i.e. from 1300 in 2016-2017 to 2100 weeds  $\text{ha}^{-1}$  in the 2017-2018 growing season) leading to this treatment having the lowest weed density in season 2 (Figure 7).

At LRS, the maize-cover crop rotations had significant effects on the total weed density in season 1 ( $P < 0.05$ ) (Table 3). Thatch grass (*Hyparr heniahirta*) and wandering jew

(*Tradescantia fluminensis*) were the predominant weed species at LRS across both seasons. Maize-pigeon pea and maize-Bambara nut rotation treatments had the highest total weed density 3200 weeds ha<sup>-1</sup> and 2450 weeds ha<sup>-1</sup> respectively in season 1 (Figure 8). Maize-velvet bean rotation together with maize-lablab and maize-cowpea rotation treatments had relatively lower total weed densities of 900 weeds ha<sup>-1</sup>, 1100 weeds ha<sup>-1</sup> and 1100 weeds ha<sup>-1</sup> respectively (Figure 8) in the first season.

There was a variable response in the number of weeds observed in the second season at the same site. There was a slight decrease in the pearl millet-jack bean rotations and a higher increase in the other treatments. The highest weed density was observed in the pearl millet-pigeon pea rotation treatment of 3200 weeds ha<sup>-1</sup> leading to this treatment having the most weed density in season 2 (Figure 9). The lowest weed density of 800 weeds ha<sup>-1</sup> was observed in the pearl millet-velvet bean treatment leading to this treatment having the lowest weed density in season 2 (Figure 9).

MASHARE 2016-2017 GRAND TOTAL WEED DENSITY

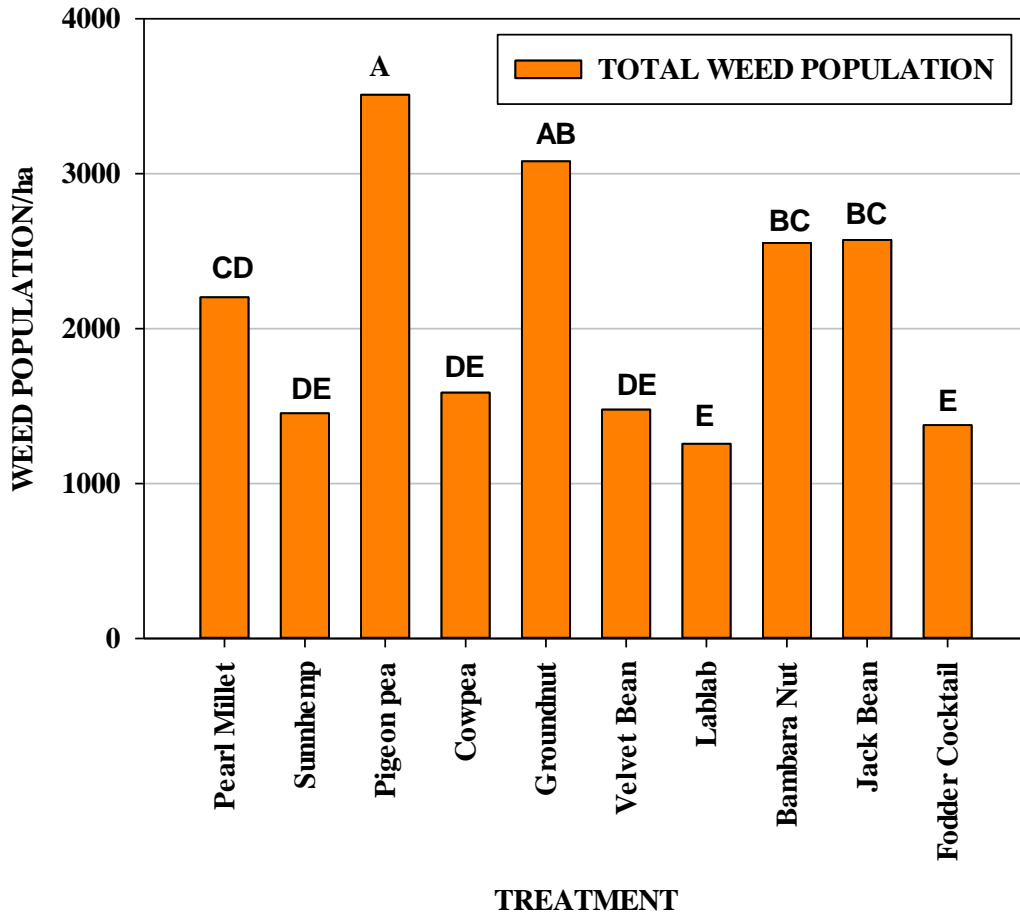


Figure 6: Effects of different pearl millet-cover crop rotations on total weed density at MITC in season one of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the first season.

MASHARE 2017-2018 GMCC GRAND TOTAL WEED DENSITY

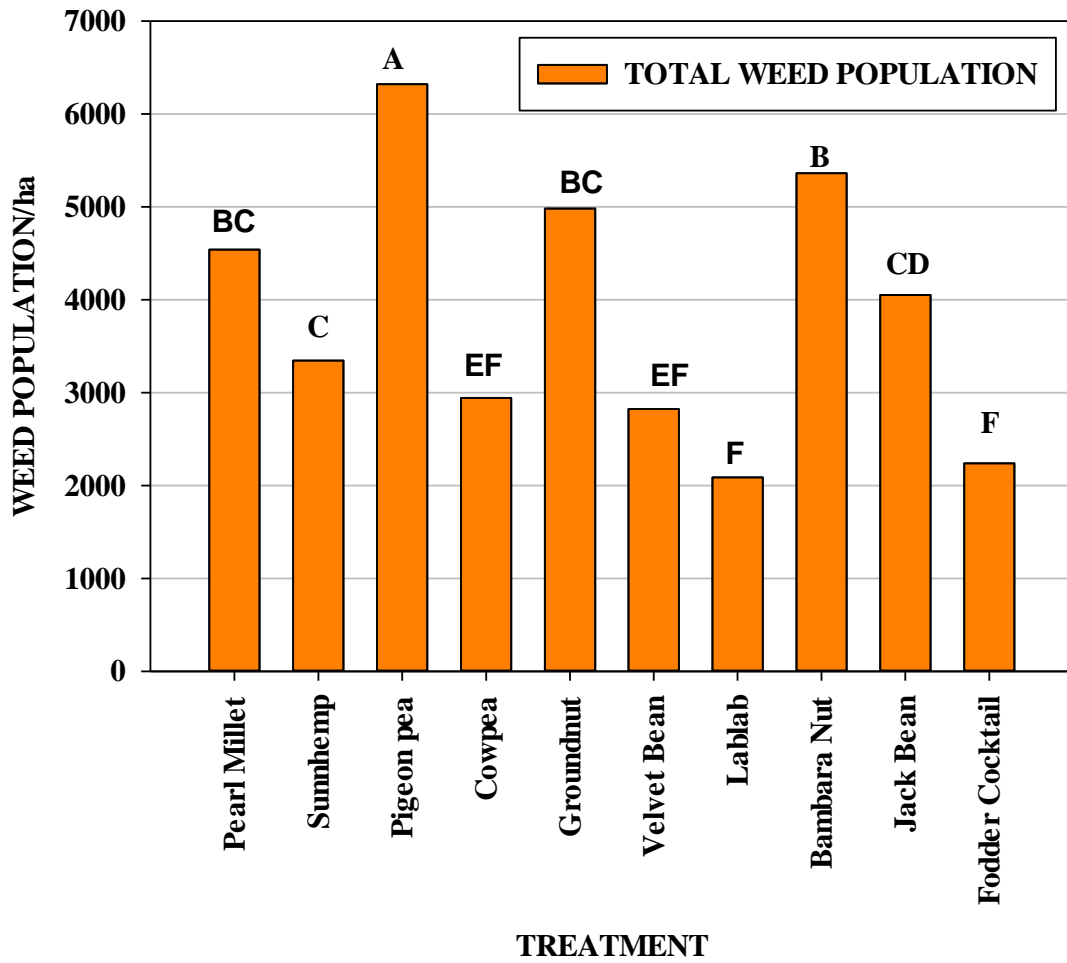


Figure 7: Effects of different pearl millet-cover crop rotations on total weed density at MITC in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2017/2018).

LISELO 2016-2017 GRAND TOTAL WEED DENSITY

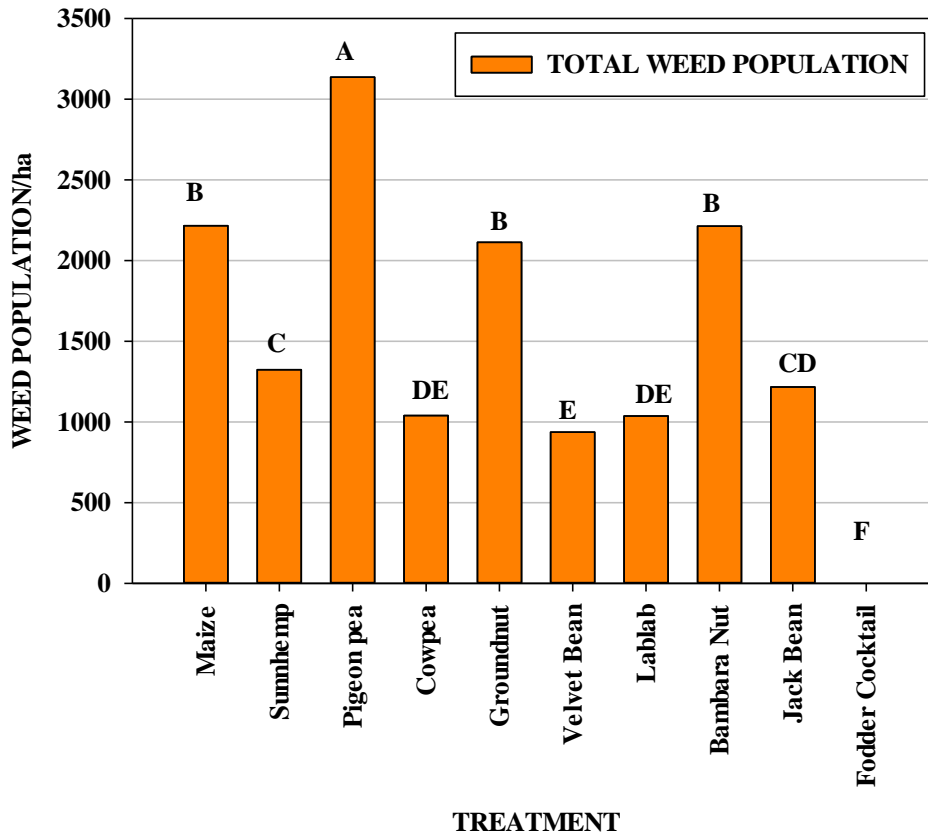


Figure 8: Effects of different pearl millet-cover crop rotations on total weed density at MITC in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2016/2017).

### LISELO 2017-2018 GRAND TOTAL WEED DENSITY

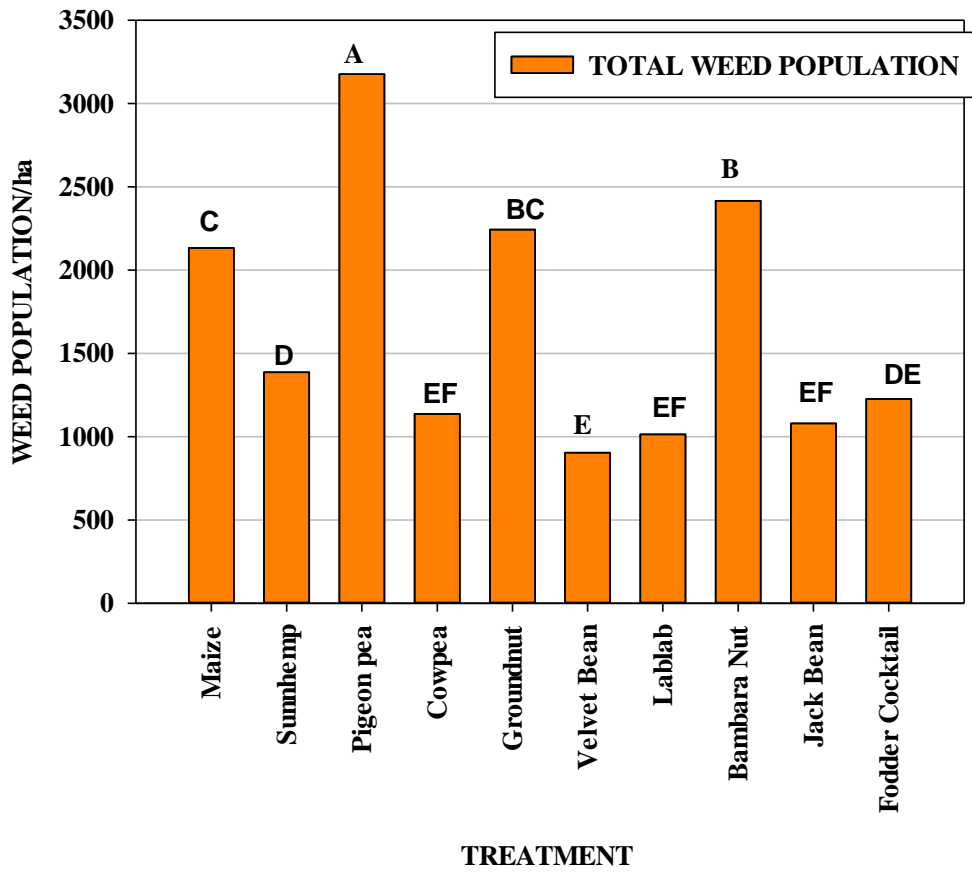


Figure 9: Effects of different maize-cover crop rotations on total weed density at LRS in season two of data collection. Different columns signify differences in the effects of the different GMCCs ( $P < 0.05$ ) on total weed density in the second season (2017/2018).

Table 1: The linear mixed model (combined model) output explaining the effects of different pearl millet and maize-cover crop rotations (treatment) and site on total weed density, total weed biomass, weed species diversity, weed species evenness and weed species richness at MITC and LRS in both season.

Total weed Density		Total weed biomass		Weed species diversity		Weed species evenness		Weed species richness			
Source	DF	F	P	F	P	F	P	F	P		
Site	1	7.81	0.006	8.31	0.01	30.59	<0.001	19.7	<0.001	85.02	<0.001
Treatment	9	3.18	0.002	4.21	0.04	1.59	0.129	0.79	0.628	1.5	0.16
Site*treatment	9	2.32	0.02	2.98	0.03	0.58	0.812	0.67	0.733	0.93	0.501

#### 4.1.2 Total weed biomass

The two sites, different pearl millet and maize-cover crop rotations and their interactions significantly affected total weed density across seasons as shown in the linear mixed model output ( $P < 0.05$ ) (Table 3). There was a general decrease in total weed biomass at both sites from season 1 to season 2 (Figure 10,11, 12 and 14). Different rotations did not significantly affect total weed biomass at both sites in both seasons ( $P > 0.05$ ) (Figure 10, 11,12 and 13).

MASHARE 2016-2017 GRAND TOTAL WEED BIOMASS

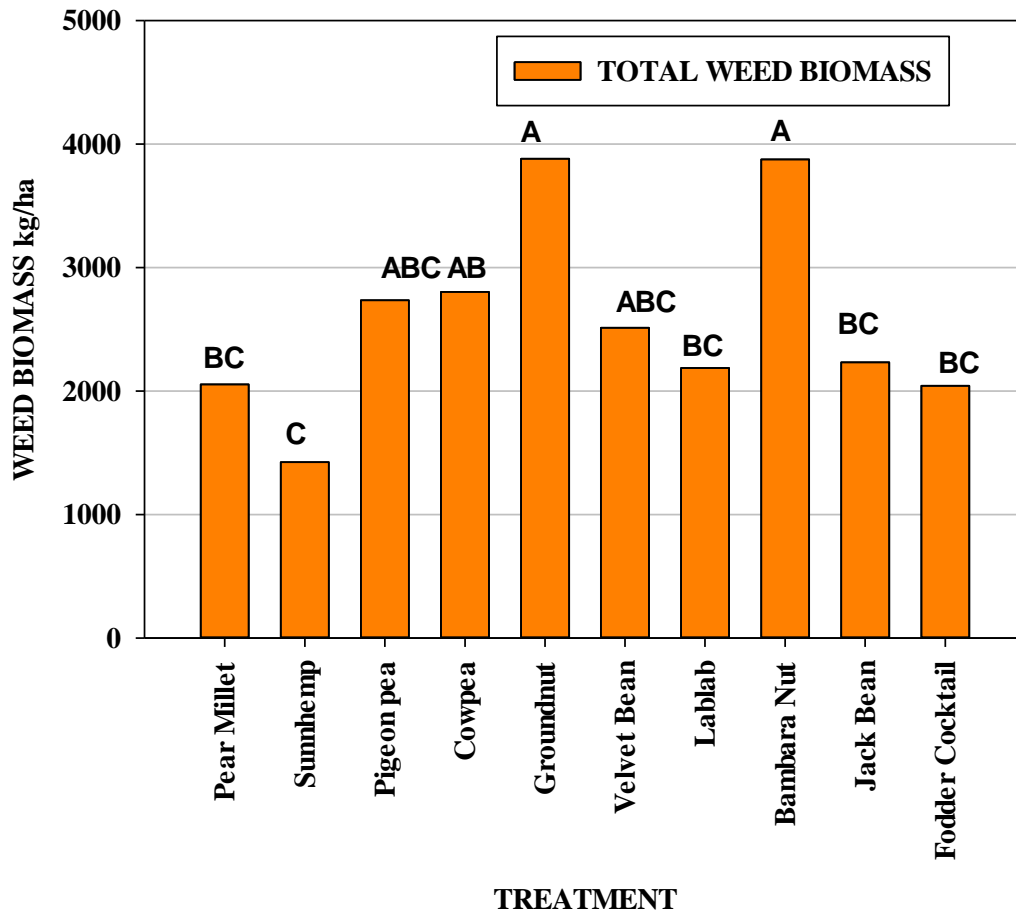


Figure 10: Effects of different pearl millet-cover crop rotations on total weed biomass at MITC in the first season of data collection.

MASHARE 2017-2018 GMCC GRAND TOTAL WEED BIOMASS

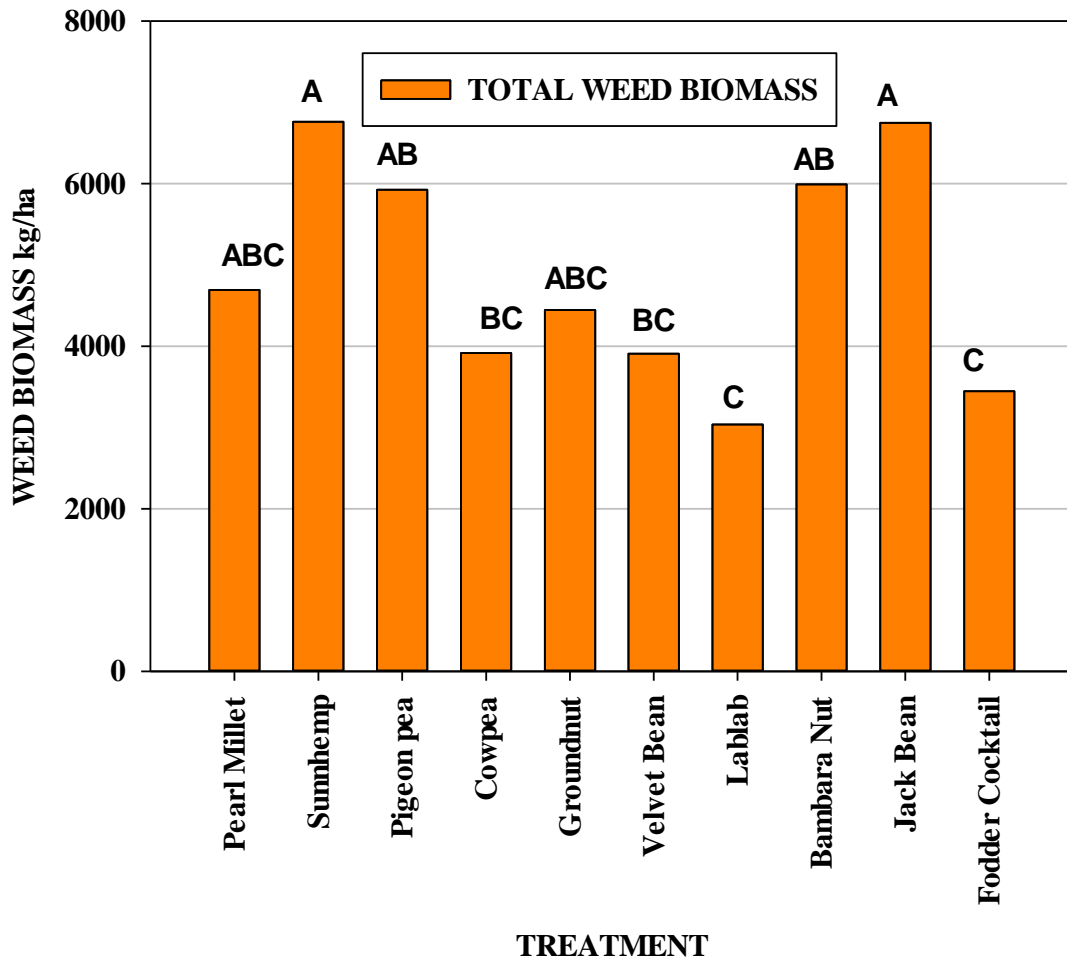


Figure 11: Effects of different pearl millet-cover crop rotations on total weed biomass at MITC in the second season of data collection.

### LISELO 2016-2017 GRAND TOTAL WEED BIOMASS

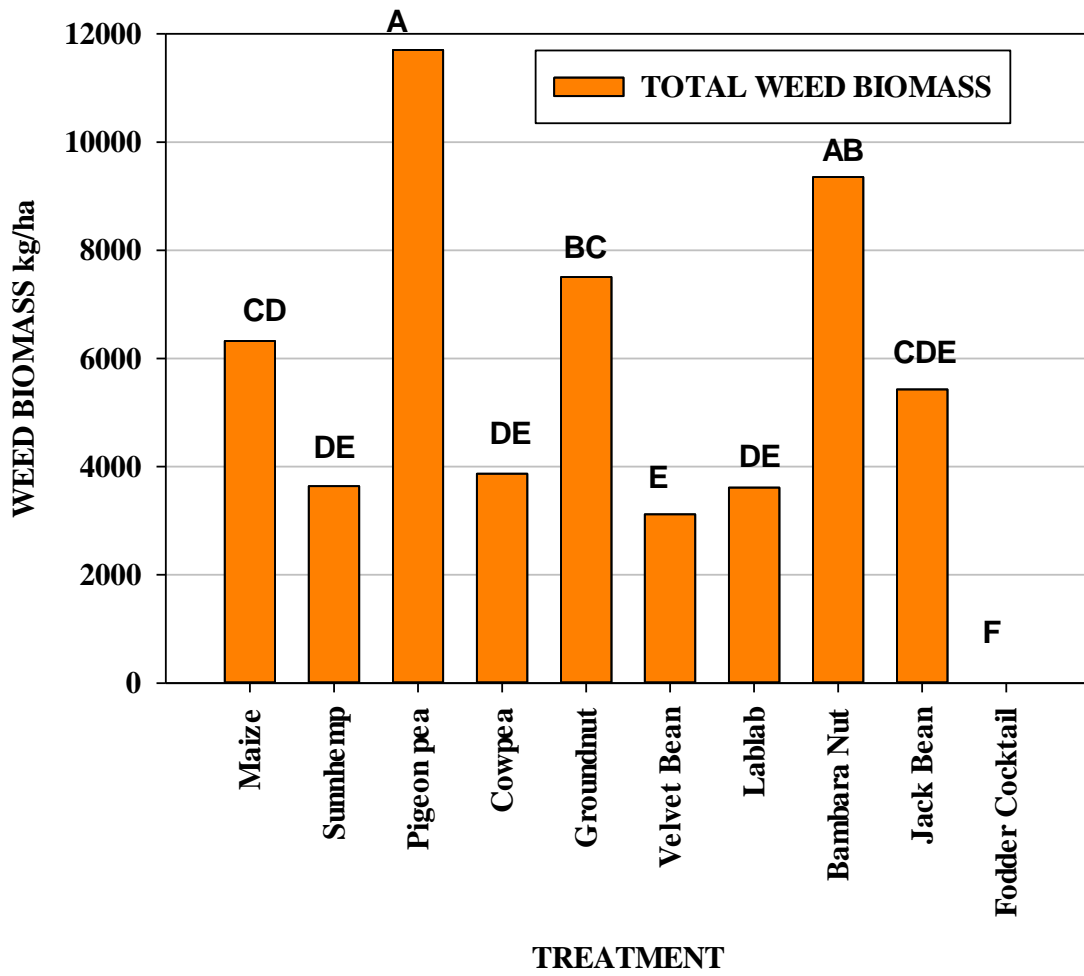


Figure 12: Effects of different maize-cover crop rotations on total weed biomass at LRS in the first season of data collection.

## LISELO 2017-2018 GRAND TOTAL WEED BIOMASS

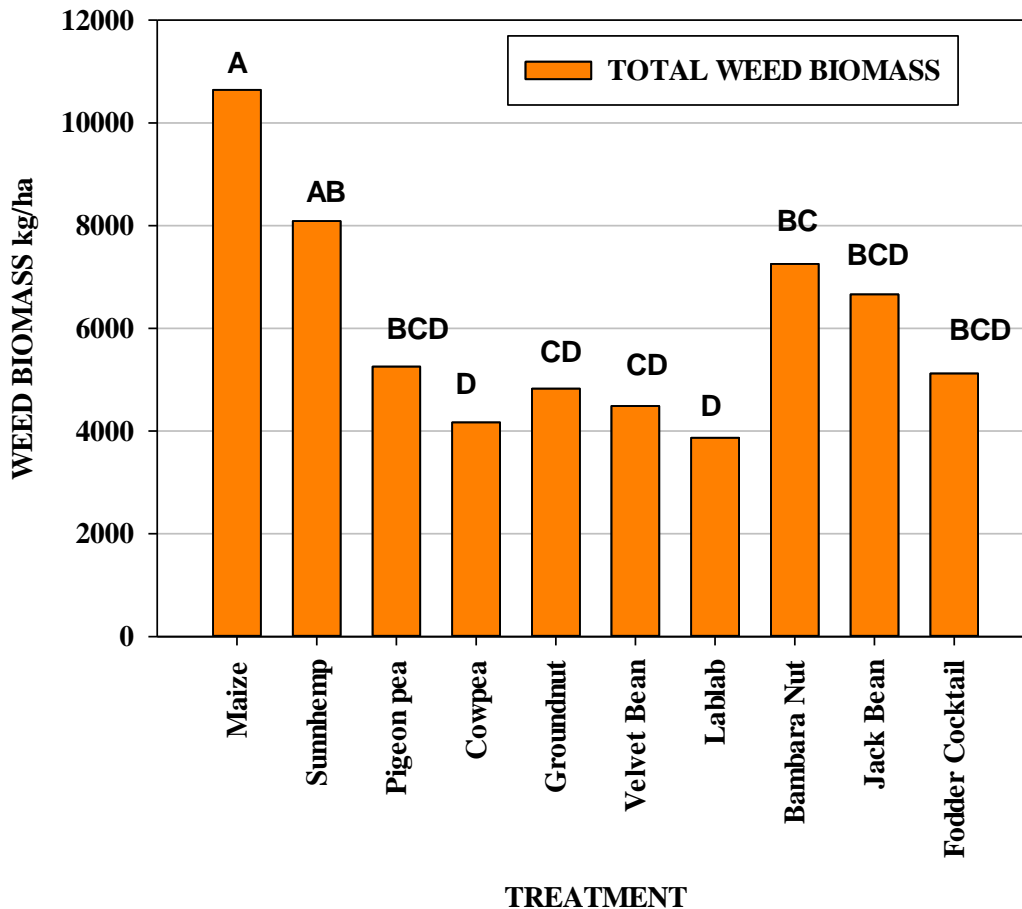


Figure 13: Effects of different maize-cover crop rotations on total weed biomass at LRS in the second season of data collection.

### 4.1.3 Predominant weed species

Numerous weed species were identified at MITC and LRS. Figure 18 shows a comprehensive composition of weed species found at both sites. Grasses in MITC were limited to three species, while broadleaf weed species were more diverse. Grass diversity was much greater in LRS, with multiple grass species often being found in the same plot. Several leguminous shrub and tree species were also found in LRS. Sedges were present in LRS, although in very small numbers, but were not present in MITC. Complete tables for estimates of medians of weed species richness and Shannon-Wiener Diversity and Evenness Index are provided in table 2.

*Trianthema portulacastrum* (L.) (Horse purslane), a perennial, spreading plant with sticky seeds, was the most dominant broadleaf weed species at MITC and was found in nearly all treatments over the course of the experiment. *Digitaria ciliaris* (Crab grass) an annual species was the most dominant grass species (Figure 18).

*Tradescantia luminensis* (Wandering jew), a perennial, spreading plant with shiny leaves, was the dominant broadleaf species at LRS and a single plant often spread across several plots. No grass species appeared to be particularly dominant. *B. massaiensis*, a leguminous shrub, was the dominant shrub/tree species at LRS (Figure 18).

#### **4.1.4 Weed species composition (Weed species diversity, evenness and richness)**

There were significant differences in weed species diversity, evenness and richness across seasons as shown in the linear mixed model output ( $P < 0.001$  for all) at the two sites (Table 1). There was a significant difference in weed species composition between the two sites. The different pearl millet and maize-cover crop rotations had no significant effects on weed species diversity and evenness at both sites in all seasons ( $P > 0.05$ ). However, there was an increase in species diversity and evenness from season 1 to season 2 at both sites (Table 2). At MITC, different pearl millet-cover crop rotation treatments significantly affected the number of species present in season 2 only ( $P < 0.05$ ) (Figure 13). The highest number of weed species of 18 species  $\text{ha}^{-1}$  was observed in the maize-pigeon pea rotation treatment and the lowest numbers of weed species were observed in the maize-black sunnhemp, maize-cowpea, and maize-jack bean rotations (Figure 13). At LRS, maize-cover crop rotations had no significant effect on the number of weed species that appeared in both seasons (Figure 13 & 14).

Figures 15 to 18 below show the effects of different Pearl millet-cover as well as different maize- cover crop rotations on weed species richness at MITC and LRS in both seasons of data collection. The different columns signify differences in the effects of the different rotations ( $P < 0.05$ ) on weed species richness at both sites and in both seasons. While (figure 19) below shows the predominant weed species at MITC and LRS in all the treatments for both seasons. In addition, the (figures 21 to 25) below show the effects of different pearl millet-cover crop rotations and maize-cover crop rotations on

grain and stover yields ( $\text{kg ha}^{-1}$ ) of the subsequent pearl millet and maize crop in season 2 at MITC and LRS.

Table 2: Effect of different pearl millet and maize-cover crop rotations on weed species diversity (Shannon's index 'H') and weed species evenness (Shannon's index 'E') at MITC and LRS in all seasons.

Treatment	MITC				LRS			
	Weed Species Diversity		Weed Species Evenness		Weed Species Diversity		Weed Species Evenness	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Millet after millet	1.42	2.25	0.30	0.49				
Maize after maize					1.25	1.27	0.25	0.27
Millet after Sunnhemp	1.01	1.90	0.23	0.46				
Maize after Sunnhemp					0.92	1.2	0.19	0.27
Millet after Bambaranut	1.33	1.73	0.28	0.37				
Maize after Bambara					1.27	1.57	0.28	0.33
Millet after groundnut	1.20	1.86	0.27	0.46				
Maize after groundnut					1.10	1.24	0.22	0.29
Millet after velvet bean	1.31	1.79	0.30	0.37				
Maize after velvet bean					1.19	1.39	0.31	0.33
Millet after pigeon pea	1.56	2.14	0.37	0.38				
Maize after pigeon pea					1.27	1.52	0.29	0.35
Millet after lablab	1.20	1.72	0.26	0.40				
Maize after lablab					1.09	1.21	0.27	0.24
Millet after cowpea	1.44	1.34	0.27	0.33				
Maize after cowpea					0.91	1.39	0.20	0.33
Millet after cowpea	1.33	1.78	0.33	0.47				
Maize after cowpea					0.58	1.49	0.12	0.36
Millet after fodder cocktail	1.25	1.58	0.24	0.37				
Maize after fodder cocktail					1.19	1.17	0.25	0.28

<i>P-value</i>	NS	NS	NS	NS	NS	NS	NS	NS
SED	0.38	0.33	0.071	0.09	0.23	0.23	0.08	0.07

NS shows that means were not significantly different from each other.

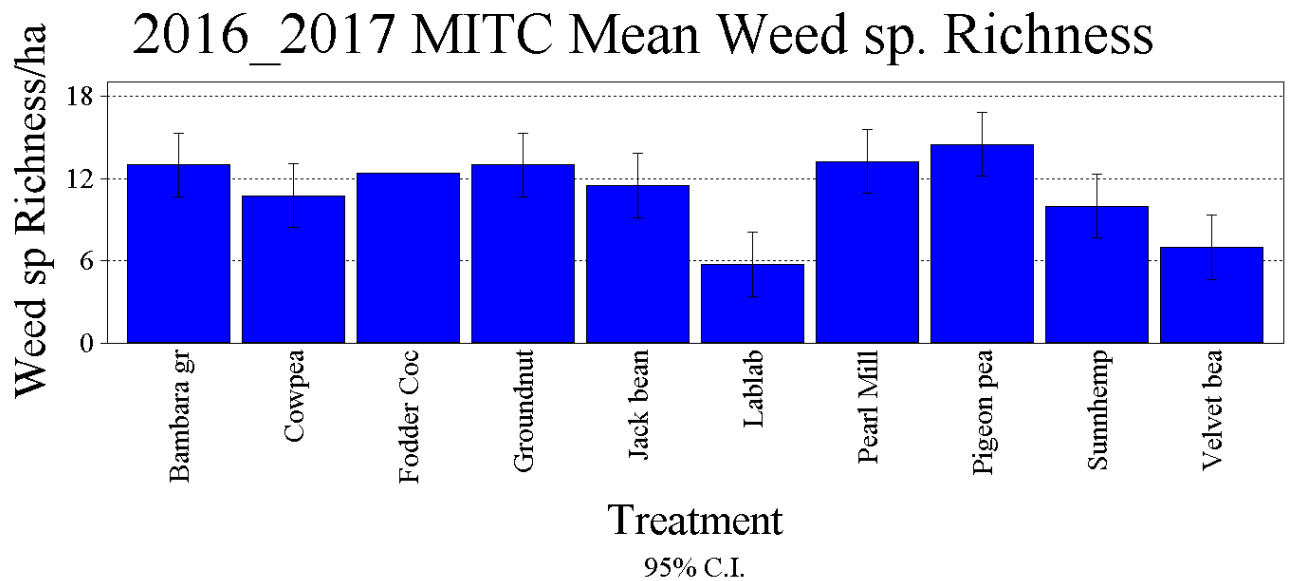


Figure 14: Effects of different Pearl millet-cover crop rotations on weed species richness at MITC in both seasons of data collection. The different columns signify differences in the effects of the different rotations ( $P < 0.05$ ) on weed species richness in each season.

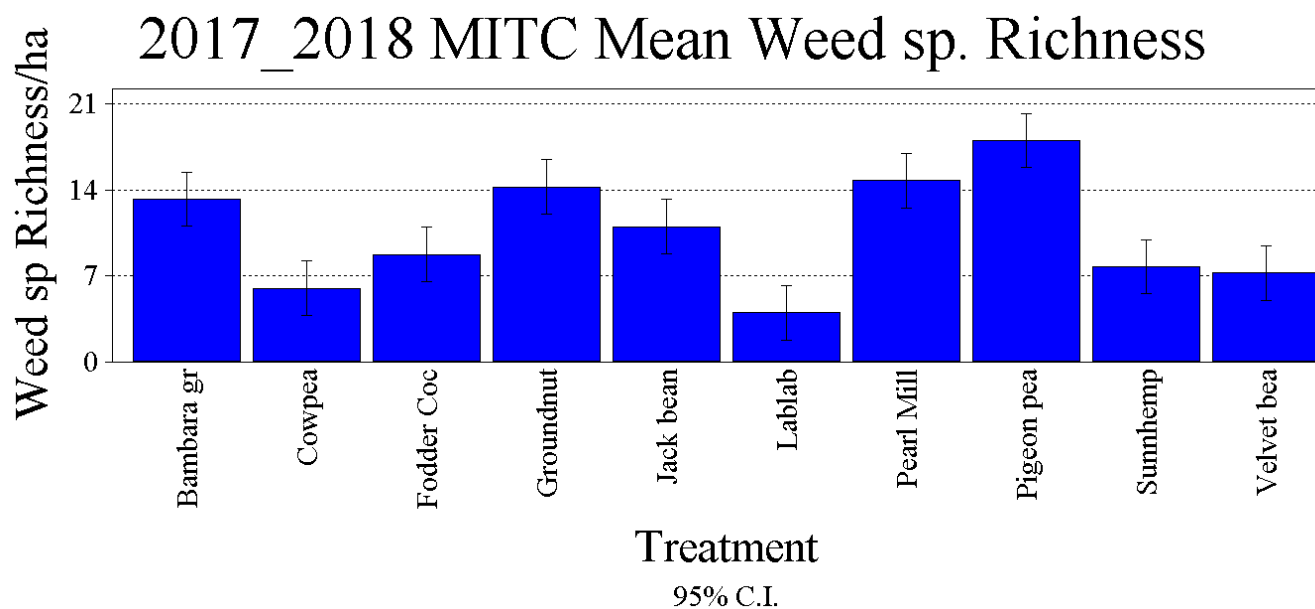


Figure 15: Effects of different pearl millet-cover crop rotations on weed species richness at MITC in the second season of data collection. The different column signifies differences in the effects of the different rotations ( $P < 0.05$ ) on weed species richness in the second season.

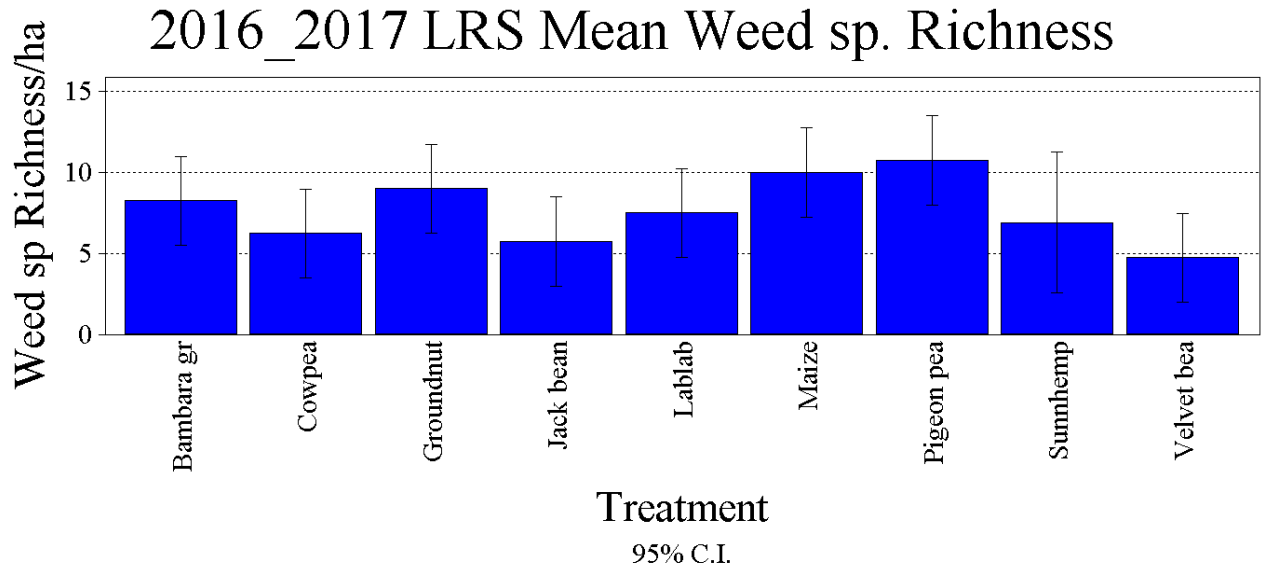


Figure 16: Effects of different maize-cover crop rotations on weed species richness at LRS in the first season of data collection.

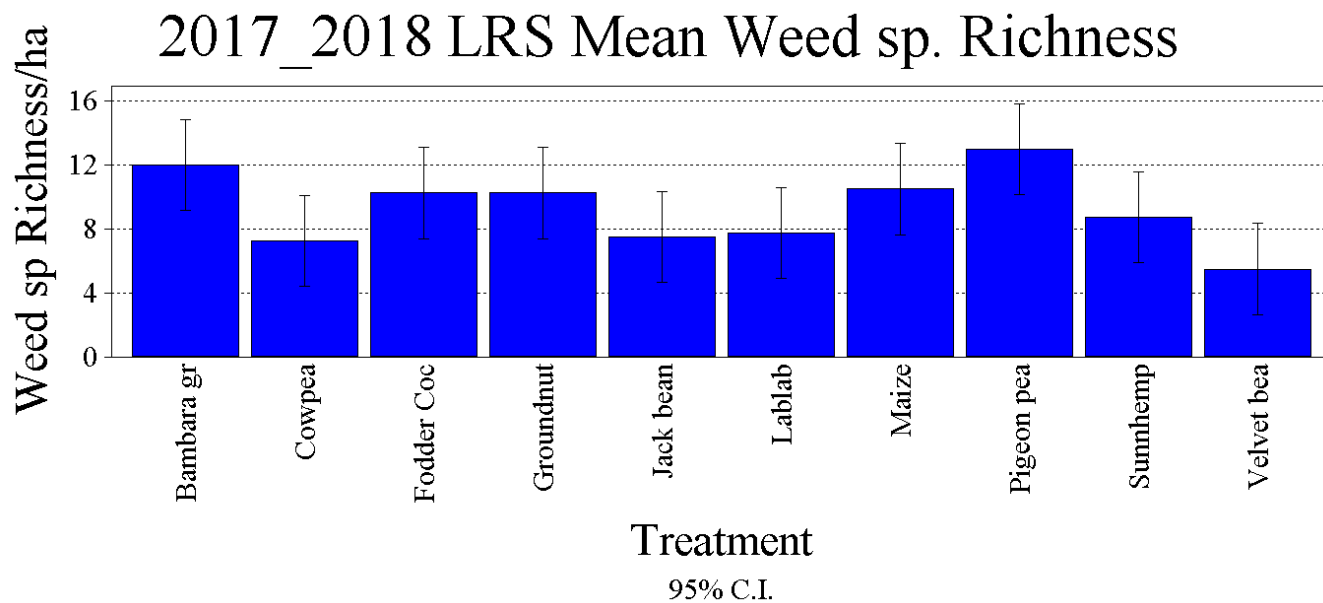


Figure 17: Effects of different maize-cover crop rotations on weed species richness at LRS in the second season of data collection.

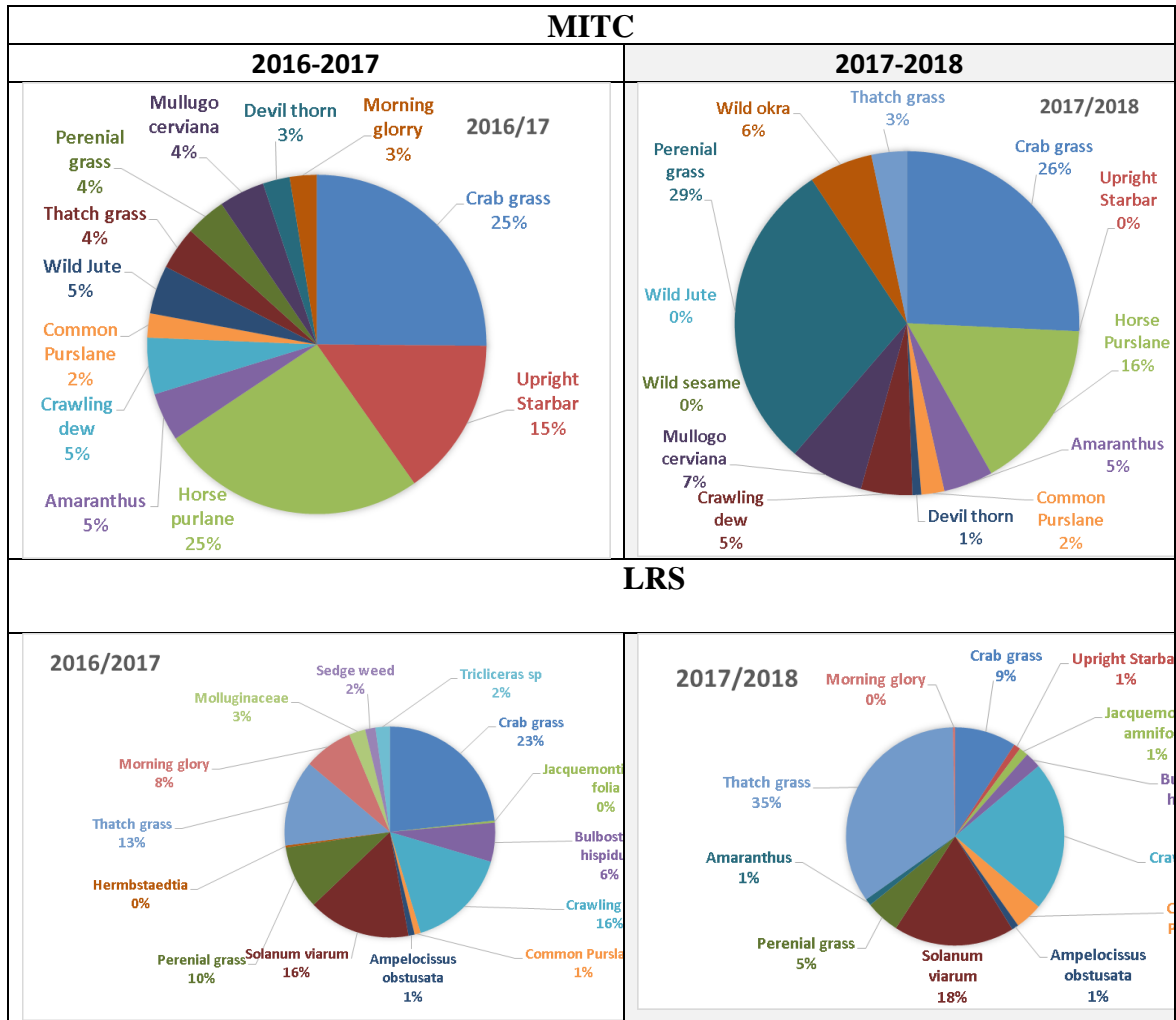


Figure 18: Predominant weed species at MITC and LRS in all the treatments for both seasons.

**4.1.4 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on GMCC grain and biomass yield.**

At both sites in season 1, there was a significant difference in the effects of rotating cover crops with pearl millet and maize on both cover crop grain and biomass yields ( $P < 0.05$ ). At MITC, lablab attained the greatest biomass yield with a mean yield of 11500 kg ha<sup>-1</sup>. The least biomass yield was observed in jack bean with a mean yield of 1000 kg ha<sup>-1</sup> (Figure 15). The pearl millet after lablab) attained the greatest grain yield, producing a yield of 3000 kg ha<sup>-1</sup>, with jack bean, bambara nut and common sun hemp producing lower grain yields (Figure 15).

At LRS, pigeon pea produced no grain and no biomass yields due to failure to establish. For the treatments that established, lablab, Bambara nut and sunnhemp had the least grain yields as low as 50 kgha<sup>-1</sup> (sunnhemp) and the greatest grain yield was attained by the control (maize after maize) producing a yield of 1300 kg ha<sup>-1</sup>. The greatest biomass yield was observed in the velvet bean treatment with a mean yield of 5900 kg ha<sup>-1</sup> (Figure 17).

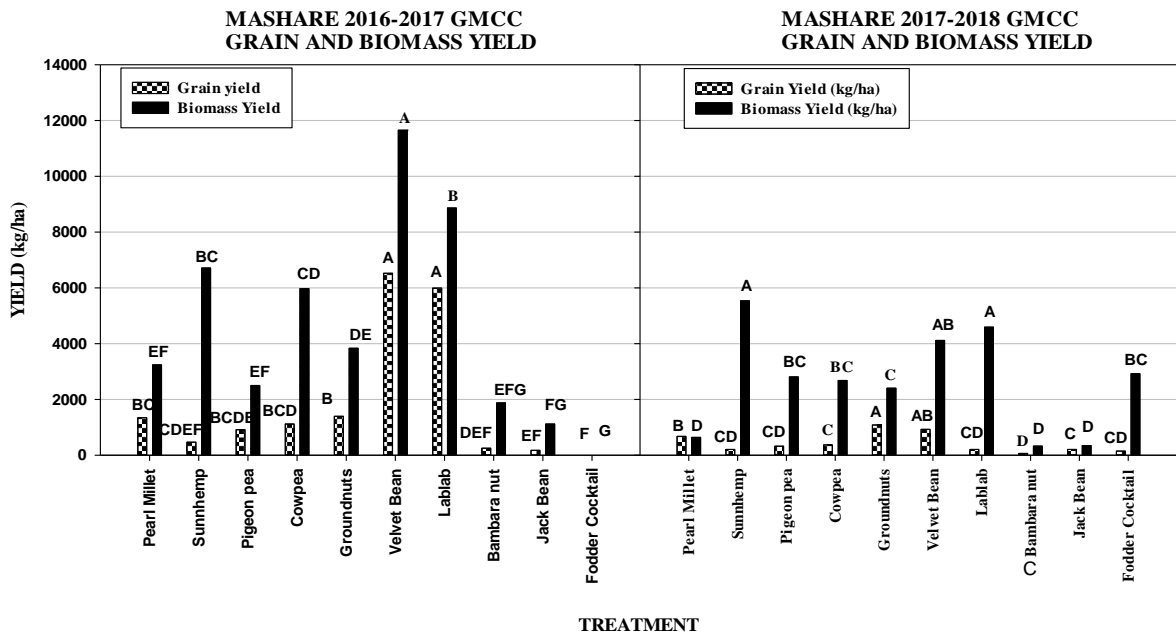


Figure 19: Effects of different pearl millet-cover crop rotations on grain and biomass yields (kg ha<sup>-1</sup>) of cover crops in both seasons at MITC. Means represented by columns are significantly different using the LSD test ( $P < 0.05$ ).

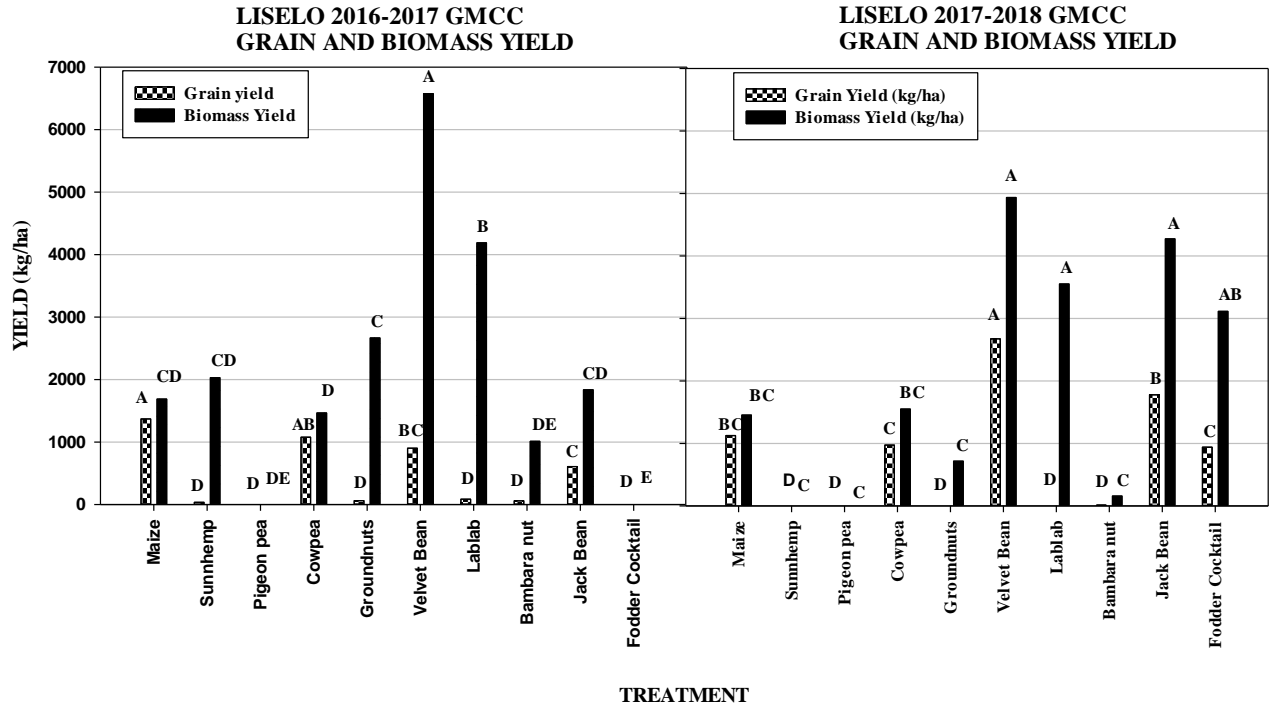


Figure 20: Effects of different maize-cover crop rotations on grain and biomass yields (kg ha<sup>-1</sup>) of cover crops in both seasons at LRS. Means represented by columns indicated by different bars are significantly different using the LSD test ( $P < 0.05$ ).

#### 4.1.5 Soil fertility

Soil NPK levels, pH, organic C, and estimated soil organic matter (SOM) were analyzed at both research sites. At both sites, soil nitrogen and phosphorous levels were below the suggested range for grains, while potassium fell within the ideal range (Table 3). Soil pH was optimal at both trial sites. Soil organic carbon was well below the ideal range.

Table 3: The soil nitrogen, phosphorous, potassium, pH, organic carbon, and soil organic matter levels at both sites. Sites, different maize and pearl millet-cover crop rotations and their interactions had no significant impact on the soil nutrient content across seasons ( $P < 0.05$ ).

	<b>Average value at MITC</b>	<b>Average value at LRS</b>	<b>Suggested range for grains</b>
<b>N (ppm)</b>	480	280	1000-2000
<b>P (ppm)</b>	<100	<100	200-600
<b>K (ppm)</b>	2800	2200	1500-3000
<b>pH</b>	6.1	5.3	4.9-6.4
<b>Organic C (ppm)</b>	2900	6900	1700-5000
<b>Estimated SOM (%)*</b>	<1	1.2	2.9-8.6
p-value	0.377	0.313	

Pearl millet was planted at the MITC experimental field, while maize was grown at LRS. The suggested range for grains is based on numbers provided in the SoilCares (2017, [www.soilcares.com](http://www.soilcares.com)) soil analysis. N = nitrogen; P = phosphorous; K = potassium; C = carbon; SOM = soil organic matter. n = 24 at Mashare Research Station; n = 24 at Liselo Research Station. The soil data was analyzed at the beginning of the experiment (2016/2017 season).

#### 4.1.6 Effects of different rotations on soil PAN contribution from GMCC residues

Different cover crop residues contributed significantly to different levels PAN to the following pearl millet and maize crops at all sites in season 2. At MITC, in season 2, Jack bean, pigeon pea and fodder cocktail had higher PAN of 1000 parts per million (ppm), 700 ppm and 650 ppm to the system. The other cover crops produced PAN not significantly different from each other (Figure 18).

At LRS, the amount of PAN depended on the type of residue. In season 2, the highest PAN was produced by jack bean residue (1300 ppm). Lower PAN (150 ppm) was obtained from maize residue although not significantly differently from velvet bean, Bambara nut, groundnut, lablab, sunnhemp and cowpea (Figure 19).

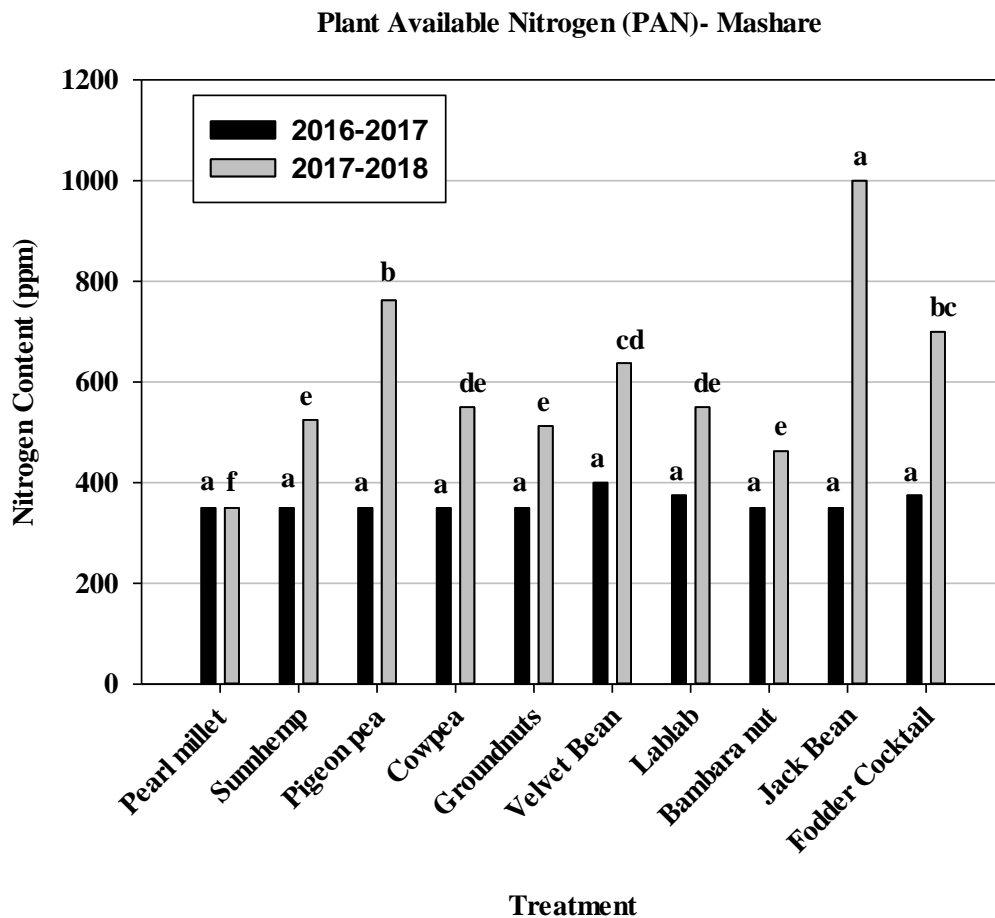


Figure 21: Effects of different pearl millet-cover crop rotations on PAN (ppm) contribution of different cover crop residue to the succeeding pearl millet crop in both seasons at MITC. Means represented by columns indicated by different letters are significantly different using the LSD test in the first season ( $p > 0.05$ ).

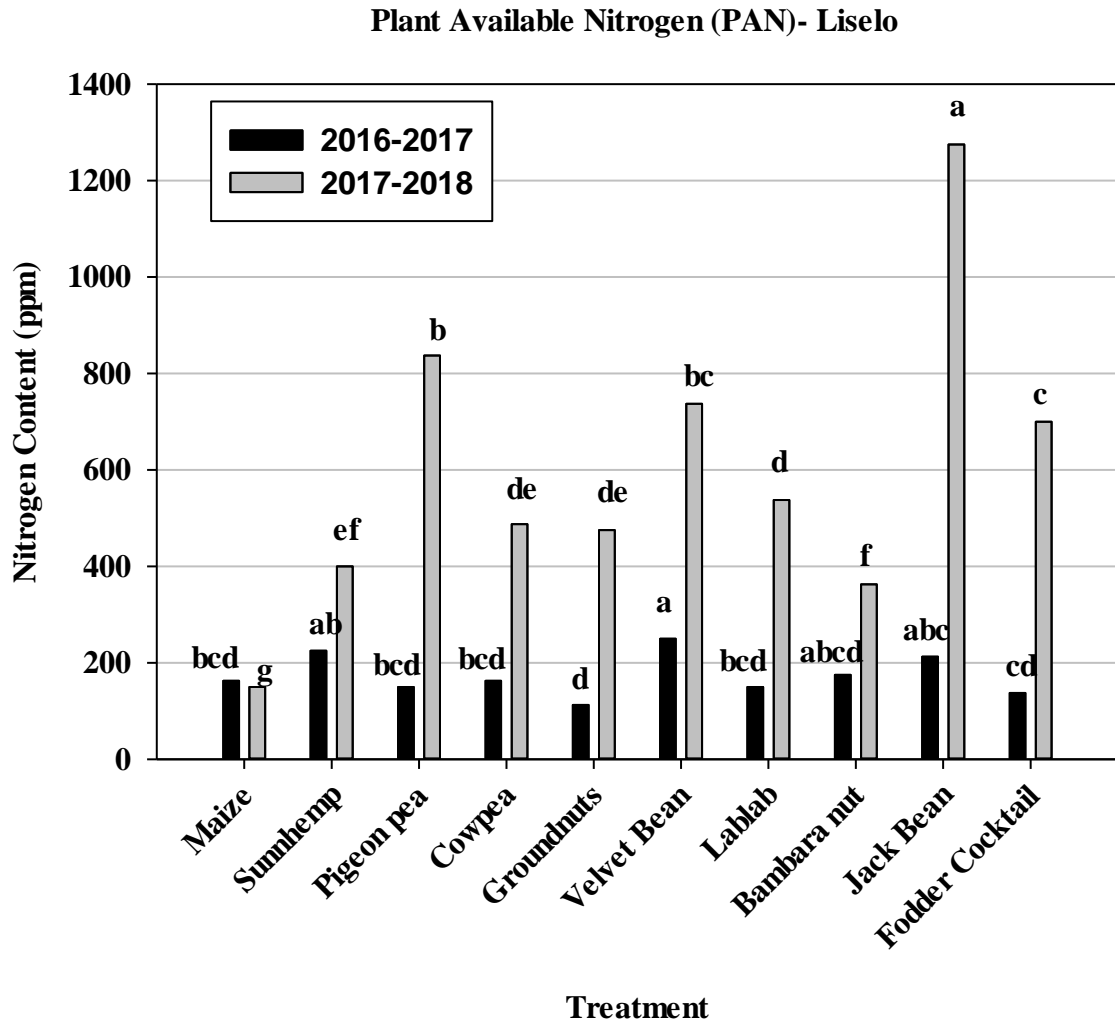


Figure 22: Effects of different maize-cover crop rotations on PAN (ppm) contribution of different cover crop residue to the succeeding maize crop in both seasons at LRS. Means represented by bars indicated by different letters are significantly different using the LSD test in the first season ( $P < 0.05$ ).

#### **4.1.7 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on grain and stover yields of the subsequent maize crop**

Uniform pearl millet was seeded in the second season at MITC, different rotations significantly affected biomass yield of the succeeding pearl millet crop ( $P < 0.05$ ). Pearl millet after pearl millet treatment had a mean biomass yield of  $700 \text{ kg ha}^{-1}$  ranking the lowest in this season at this site (Figure 18). Different rotations had no significant effects on pearl millet grain yields of the succeeding pearl millet crop in this season (Figure 20). At LRS, different rotations had no significant effects on both maize grain and stover yields in season 2 (Figure 21).

### MASHARE 2017-2018 PEARL MILLET AFTER GMCC GRAIN AND BIOMASS YIELD

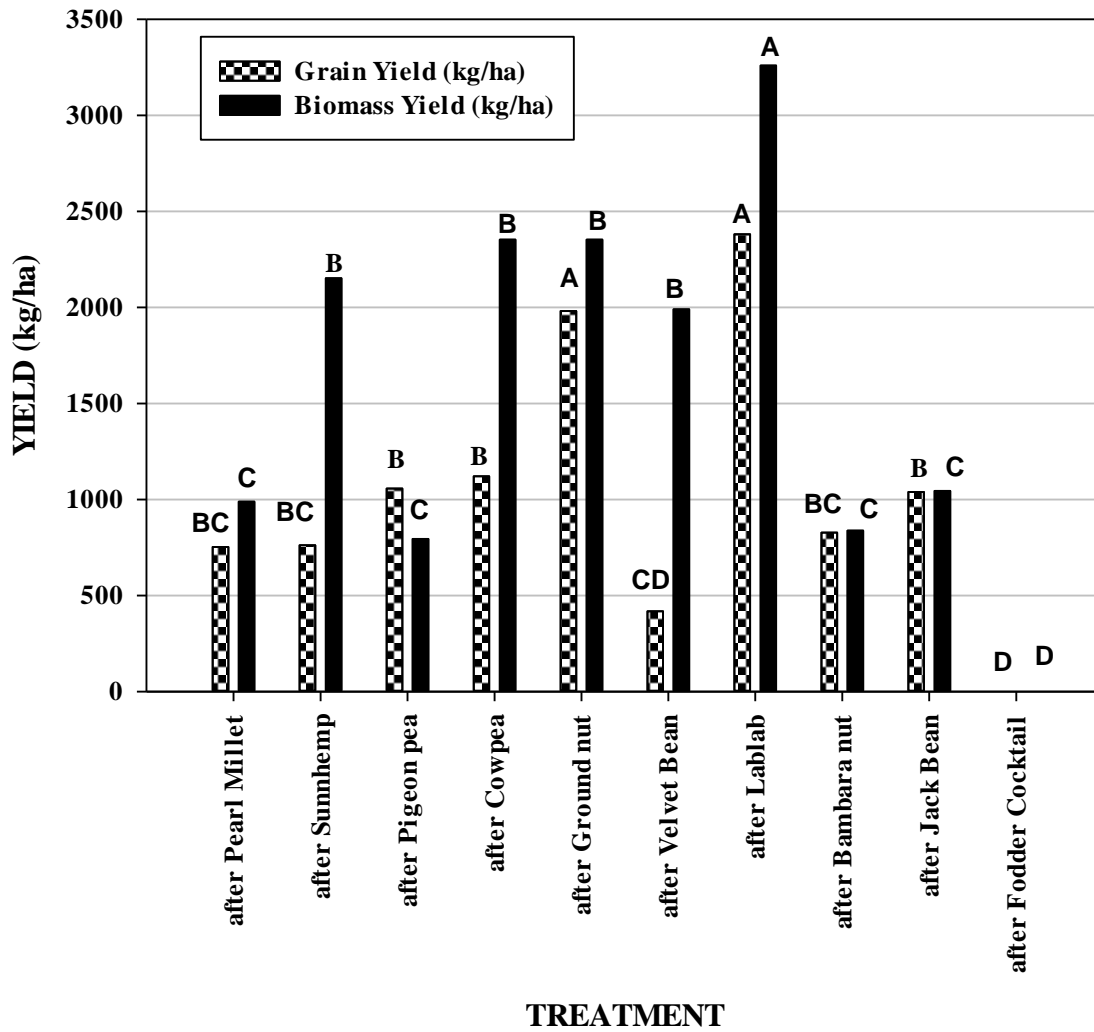


Figure 23: Effects of different pearl millet-cover crop rotations on grain and biomass yields (kg ha<sup>-1</sup>) of cover crops in season 2 at MITC. Means represented by columns indicated by different bars are significantly different using the LSD test ( $P < 0.05$ ).

**LISELO 2017-2018 MAIZE AFTER GMCC  
GRAIN AND BIOMASS YIELD**

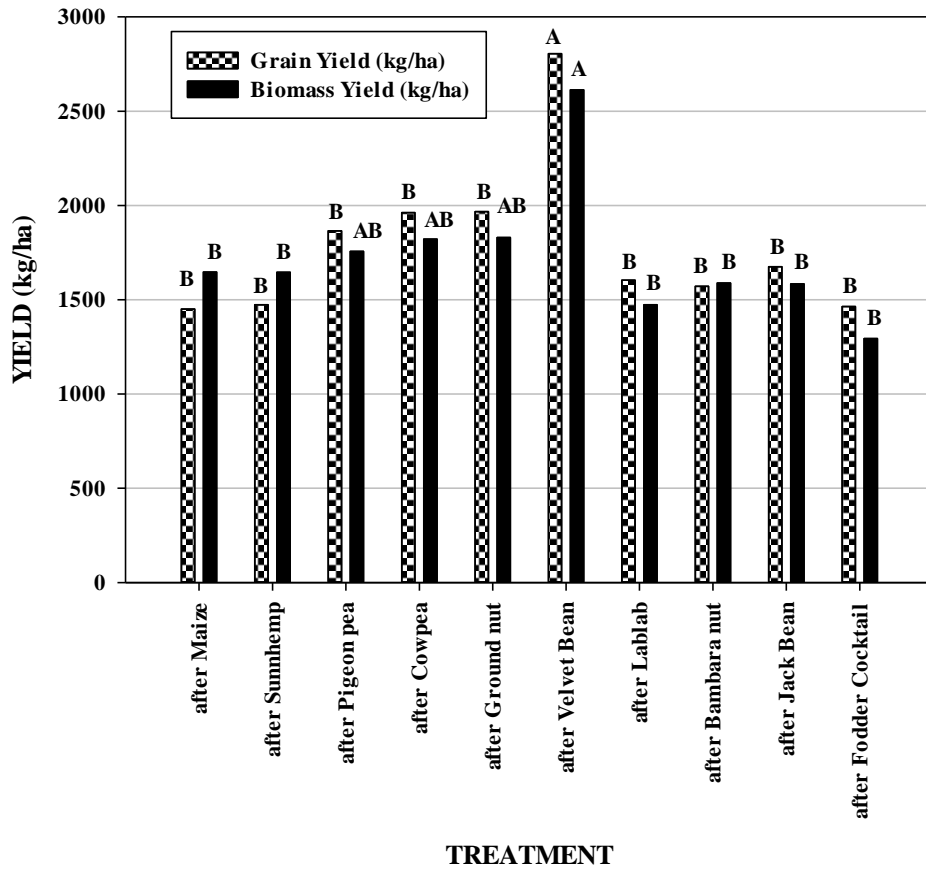


Figure 24: Effects of different maize-cover crop rotations on grain and stover yields (kg ha<sup>-1</sup>) of the subsequent maize crop in season 2 at LRS.

## CHAPTER FIVE

### 5.0 DISCUSSIONS

The aim of the study was to determine the effectiveness of different leguminous and non-leguminous GMCC/ fodder crops, grown in rotation with pearl millet and maize, in ensuring adequate residue cover and considerable fodder supply and to quantify their effects on pearl millet and maize productivity and weed suppression. The study assessed the effect of GMCCs on weed smothering (weed density), weed composition (weed species diversity, evenness and richness), the effect of GMCCs on the soil Nitrogen content for both seasons, and the yield variation of pearl millet and maize in the second season (after GMCCs rotations). This section seeks to address the research objectives and answer the research questions based on findings from the study.

#### **5.1 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on total weed density, total weed biomass and composition.**

##### **5.1.1 Total weed density**

The management of weeds using rotations with cover crops mainly depends on the ability of cover crops to smother weeds (Teasdale, 1998). Teasdale *et al.*, (2007a) on the contrary argue that cover crops use different mechanisms in weed smothering either as live cover crops or as residues, but live cover crops have been revealed to have a more suppressive effect on weeds. Reactions in weed numbers was determined by the nature of the rotation i.e. the cover crop involved in the rotation. In addition, (Teasdale & Mohler, 1993) also argue that cover crop residues present physical hurdles that inhibit the emergence of weeds leading to reduced weed numbers over time.

Since the cover crops involved in the rotations were treated as grain legumes, pigeon pea was harvested last thus allowing longer time for more nitrogen to be fixed in the soil and subsequently promoting more weed growth in the first season of data collection. The high weed numbers in the pearl millet-Bambara nut rotation treatment may be due to the less vigorousness of the legume and may also be attributed to the growth cycle of Bambara nut, which is one of the shortest, compared to the other cover crops in this

study henceforth leading to high weed numbers. Weed suppression in the second season (season after cover crops) mainly depended on the amount and nature of the various cover crop residues (Hartwig & Ammon, 2002).

The increase in the number of weeds in the maize after maize and maize-pigeon pea treatments in the second season of data collection could mainly be due to the nature of the cover crop residue. Teasdale & Mohler (1993) also reported that pigeon pea and pearl millet residues leave more interior spaces due to their nature and this allows for the emergence of weeds that need light for a phytochrome-mediated germination leading to higher numbers compared to residue of lablab. They further argue that jack bean, velvet bean and lablab residues may also have produced nitrates during decomposition that encouraged the emergence of certain weed species leading to increased weed numbers in the following maize crop. According to Skinner *et al.*, (2012) black sunn hemp has been reported to have allelopathic effects on certain weed species such as smooth pigweed (*Amaranthus hybridus* L.) and this may explain the high decline in the number of weeds observed in the second season. The decline in the weed density in the maize-jack bean treatment may be due to the high biomass production of the cover crop leading to high smothering levels (Teasdale *et al.*, 2007a).

### **5.1.2 Total weed biomass**

The decreases in weed biomass at both sites may be due to decreases in weed densities. Furthermore, different rotations had no significant effects on weed biomass at both sites in all seasons and this may be due to the effects of hand hoe weeding on time (Mhlanga *et al.*, 2017). Weeds have different biomass yield capabilities, hence since weeding was done after the same period of time in all treatments, it allowed for weeds at this site to grow to the same height and weight before weeding; therefore, there was no significant differences observed on the weights of the weeds (Muoni *et al.*, 2013).

### **5.1.3 Weed composition (Weed species diversity, evenness and richness)**

Weed species diversity, evenness and richness was reliant on the seed bank at each site. The reaction of diversity, evenness and richness depended on the weed species in their corresponding communities. Mall and Singh (2014) state that the dissimilarities in weed

densities observed at different sites may be ascribed to different seed banks establish in those sites. According to (Teasdale and Mohler, 1993) crop residue retention, in spite of their type, changes the micro-environment around weed seed bank by either promoting or preventing their emergence. Stevenson *et al* (1997) further recognized that the increases in weed diversity and evenness were due to the declines in numbers of certain dominant weed species. In addition, (Teasdale and Mohler, 1993) state that there are weed species that require more light to undergo a phytochrome-mediated germination before their emergence, therefore in the presence of live cover crops, these weed species may not emerge.

When pearl millet and maize were introduced in the second cropping season, there was reduced cover and these weeds were to be expected to emerge since cover crops in their live state are more exploitive than their residues (Teasdale *et al.*, 2007a). Weed species such as *Trianthema portulacastrum* (L.) Horse purslane emerged in the system with time reducing the chances of dominance of certain weed species. This increased diversity, evenness and richness. These weed species also added in the increasing species richness at both sites. The increases were more evident in the pearl millet after pearl millet, maize after maize, and as well as in the maize-pigeon pea rotation treatments due to the nature of the cover crop residue, which leave more internal spaces allowing for more access of light, by the weed seeds. A similar trend of results was also reported by (Ulber, L., Steinmann, H.-H., Klimek, S., Isselstein, J, 2009) in which the number of weeds increased with time in organic crop rotation systems.

#### **5.1.4 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on GMCC grain and biomass yields.**

The difference in biomass production of the cover crops was predominantly due to their differences in morphology and their ability to exploit their surrounding environment. Leguminous cover crops fixed nitrogen and this ensured high biomass productivity and this is the This is the reason for the higher biomass yields (Hartwig & Ammon, 2002). However, pearl millet biomass in the first season was higher than jack bean, Bambara nut and pigeon pea due to the additional top dressing applied to the pearl millet control crop. The very low yields witnessed in the black sun hemp treatment at MITC and total

crop failure at LRS was due to wilting which could have been caused by the persistent dry spell experienced between January and February or it could have been triggered by a fungal disease such as *Fusarium udam* (Clark, 2007).

#### **5.1.5 Effects of different rotations on PAN contribution from GMCC residue**

Plant available soil nitrogen from the cover crops depended on percentage of N content of the cover crop residue and dry matter yield (Sullivan *et al.*, 2011). Since pearl millet and maize are non-legumes and hence have a low N content in their residues, hence their soil contained low plant available N from their residues (Hartwig & Ammon, 2002). High PAN values obtained from cover crops such as jack bean and pigeon pea may be due to the high percentage of N in the residues and the high biomass that they produced (Okito *et al.*, 2004).

#### **5.1.6 Effects of rotating pearl millet and maize with different GMCC/ fodder crops on grain and stover yields of the subsequent pearl millet and maize crop.**

There was a yield advantage of rotating pearl millet and maize with leguminous cover crops shown by the study at MITC. Pearl millet that succeeded leguminous cover crops had higher grain yields compared to pearl millet that succeeded pearl millet. The same observation was also made at LRS, as the maize following legumes also benefited from the nitrogen that was fixed by the previous legumes and contained in the residues of the covers and released during their decomposition (Okito *et al.*, 2004). As ascertained by Wortman, 2012, pearl millet and maize following a legume has a yield advantage over pearl millet and maize that follows pearl millet and maize.

The N fixed biologically by the different cover crops was limited in the cover crop residues and released as the residues decompose thus benefiting the subsequent pearl millet and maize crop (Aber *et al.*, 1990). The existence of cover crop residue improves the soil physical characteristics such as the infiltration of water and helps in the build-up of organic matter (Mapfumo, P., Mtambanengwe, F., Vanlauwe, B., 2007) thereby guaranteeing increased in yields of the succeeding pearl millet and maize crop.

However, the availability of N from cover crop residue in rotation systems depends on other biotic and abiotic factors such as rate of decomposition (Karberg, N.J., Scott, N.A., Giardina, C.P, 2008) and this explains why pearl millet and maize that succeeded a cover crop producing the highest PAN did not necessarily yield the highest grain yield. The lack of significance of rotating with cover crops compared to maize monocropping at LRS could be due to environmental factors that affected the release of N to the maize at the right time.

#### **5.1.7 Potential weaknesses of GMCC under agro-ecological conditions**

Nitrogen availability has allowed the strengthening agricultural and it has led to an increase in the production of agro-ecological systems (Thierfelder and Wall, 2010). However, about 50% of the nitrogen fixed in to the soil by GMCCs is lost from the cultivated surroundings (FAO, 2008a). Efforts have been dedicated to advance to the efficient use of nitrogen in the agricultural system, but nothing much has improved over the past few decades (Tittonell *et al.*, 2012). The diversification of crops, using cover crops to provide a number of ecosystem functions, including the biological nitrogen fixation, could maintain yield while reducing cost (Teasdale *et al.*, 2007a). However, the system of using green manure cover crops is seen to be inefficient and unsustainable to farmers. It was also reported that a number of farmers do not really notice much of a difference in terms of their yields or their operational cost reducing when they have incorporated the use of GMCCs into their farming system (FAO, 2012c).

#### **5.1.8 Limitations of the study**

Though the results of the experiment did provide fascinating findings, the study faced some limitations. Firstly, weed dynamics are intensely affected by a number of factors that includes rainfall, soil type, pre-existing weed composition, and weed-crop competition(Mhlanga *et al.*, 2017). Thus, in order to gain a more complete picture of which GMCCs consistently result in reduced weed pressure, a study would need to be conducted over a longer period than only two growing season. Because of the length of the study, the impacts of all CA components, such as the effect of mulch on weed dynamics were not studied. In addition, drought at both sites during the study period

resulted in incomplete data (in the case of the wilting of the fodder cocktail in the first season at both sites) and was not an accurate reflection of a typical growing season.

Weed biomass and density measurements appeared to be more accurate than visual weed assessments at approximating weed species dynamics. The accuracy of weed biomass and density measurements could have been improved by increasing the number of quadrats used. However, as highlighted by Barbour *et al.* (1999) and Bonham (2003), quadrat numbers are often limited due to time and resource limitations. Because weed counts were a time-consuming and labor intensive process, increasing the number of quadrats per plot would have been impractical.

Although the study assessed the effectiveness of different leguminous and non-leguminous GMCC/ fodder crops, grown in rotation with pearl millet and maize, in ensuring acceptable residue cover and considerable fodder supply and to quantify their effects on pearl millet/ maize productivity and weed suppression, it did not account for the effects on soil microorganisms (e.g. diatoms), micro-fauna (e.g. nematodes), or meso-fauna (e.g. earthworms). The impacts of GMCCs on the biodiversity of soil organisms are not fully understood and appear to be quite variable. A study in Texas, USA found no adverse effects on microbial activity or mass following GMCC rotations (Haney, Senseman, Hons, & Zuberer, 2000). Red sunnhemp resulted in impermanence rates of up to 57% in entomopathogenic nematodes in Spain (García-del-Pino & Morton, 2017). While effects on soil microorganisms were outside the scope of this study, including this aspect would have provided a clearer picture of the environmental impacts resulting from the effect of different GMCCs.

The quality of the analyses would possibly have been improved by using more modern technological practices. However, the current methods used in the study were more appropriate for settings with limited resources and continue to be used in research trials in the developing world (Zhang, J., Zheng, L., Jäck, O., Yan, D., Zhang, Z, Gerhards, R., & Ni, H, 2013). In addition, as all samples underwent the same processes, the errors throughout were consistent and still provided satisfactory information to draw conclusions.

In addition, the results of this study may have differed if the study was conducted on farmers' fields, rather than in controlled research sites from weedy fallows. Farmers' fields would likely have lower initial weed pressure due to continuous use and cultivation. Because farmers' fields can also vary significantly in terms of weed composition and management practices, examining weed dynamics in several farmers' fields would likely present a true reflective of weed responses to different GMCCs.

## CHAPTER SIX

### 6.0 CONCLUSIONS

Converting from conventional agriculture to conservation agriculture often results in increased weed pressure, leading to an additional labor problem for smallholder maize and pearl millet farmers in northern Namibia. This study aimed to fill a knowledge gap by evaluating the effectiveness of different leguminous and non-leguminous GMCC/ fodder crops, grown in rotation with pearl millet and maize, in ensuring sufficient residue cover and substantial fodder supply and to quantify their effects on pearl millet/maize productivity and weed suppression. While no cover crop was observed to be optimal for all the areas investigated, some cover crops outperformed others. This section highlights the overall findings from the study, provides recommendations for smallholder farmers adopting or practicing CA in northern Namibia, and ends with propositions for forthcoming research.

The study stressed that rotations combined with well-timed weeding reduce weed densities over a period of time, thus rejecting the first hypothesis that stated that there was no significant difference on the effect of different GMCCs on weed suppression. Equally important, an increase in weed species diversity showed that rotations are capable of reducing numbers of dominant weeds to levels of the other non-dominant weeds and this reduces the existence of a few problematic weeds resulting into a less intensive weeding plan. Hence, the study rejected the second hypothesis that stated that there was no significant difference on the weed species diversity, evenness and richness in the various GMCC treatments. Furthermore, rotations have different effects on the components of weed diversity and ultimately leading to a reduced weed populations. A reduction in the number of weeds was also realized in the continuous pearl millet and maize plots, suggesting that residue retention combined with timely weeding may also reduce weeds in a cropping system even if a farmer cannot practice rotations. Different green manure cover crops fixed different amount of nitrogen in to the soil, affecting the plant-available soil nitrogen (PAN) differently. Hence, the study rejects the third

hypothesis that stated that there was no significant difference on the effect of the different GMCCs (PAN).

Rotating pearl millet and maize with cover crops increased pearl millet and maize yields by supplementing nitrogen. The study rejects the fourth hypothesis that stated that there is no significant difference on the effects of GMCCs on above-ground biomass and grain production of pearl millet and maize crops. This benefits poor farmers who cannot afford to buy expensive mineral fertilizers and herbicides. They can then move on to incorporate green manure cover crops into their farming systems.

## 6.1 RECOMMENDATIONS

Indeed, rotating pearl millet and maize with cover crops may be a challenge to smallholder farmers who may find it unfeasible to replace a staple crop with non-food legumes. Most of the studied cover crops in this study were non-food crops and this means in rotations, farmers will have to miss a season of pearl millet and maize. These rotations may only be feasible if farmers' have land of high holding capacity, and the land is big enough such that they, in some seasons, have uncultivated land or if they have livestock and really need the fodder. These untilled rations can then be used in the establishing cover crop rotations such that in every season they have both the cover crops and the pearl millet or maize while at the same time increasing the crop productivity. Rotations may also be practical if they are able to double the pearl millet and maize yields, so that during the season that the farmers do not have pearl millet and maize. Their yield is reimbursed for by the doubled yield they obtained in the previous season. However, in the study done, the pearl millet and maize yields were increased but not high enough to double the yield. Relay cropping of cover crops such as velvet bean in standing pearl millet and maize crop could be a possibility of introducing cover crops in the cropping systems without completely replacing the staple pearl millet or maize in each and every season.

If a farmer has a big piece of land, rotations with leguminous cover crops can be used to improve productivity of pearl millet and maize-based systems. Farmers may develop two-phased rotations in which they have both the pearl millet and maize crop-cover crops in the same season and interchanging them over the seasons. In circumstances where farmers cannot afford mineral fertilizers and herbicides, they may also use rotations with GMCCs as opposed to monocropping cereal crops. This would give them more yields compared to monocropping without any fertilizers and herbicides and allow them to have a more viable weeding management plan. All in all, there was no single cover crop that gave benefits to all the parameters investigated, signifying that there is a need to identify certain areas and a suitable cover crop suitable for that specific area before integrating them into the system. Since GMCCs have high biomass yields, cover

crops such as lablab, velvet bean and cowpea contribute significantly to supplemental biomass that can be used to cover the soil and other uses within a domestic set up.

Although this study provided thought-provoking initial discoveries, results from a two season-long agricultural trial cannot really be used to make decisive assertions regarding the effectiveness of GMCCs in pearl millet and maize-based cropping systems. It would, therefore, be advantageous to conduct a long-term study on the topic to provide a more complete picture of the interactions between treatment and site and to determine dependability of treatment effects, as well as long-term insinuations for weed population dynamics. A study on the incorporation of other weed control strategies, such as chemical, mechanical or cultural control or the use of different weed removal mechanisms, such as weed scrapers, would additionally contribute to today's knowledge. As recommended, weed management would likely benefit from the integration of several weed control strategies, but optimum methodologies would first need to be acknowledged. Finally, a total life cycle analysis of differing GMCCs, including agro ecological and socioeconomic consequences, would contribute to a more complete picture of the relationships and complexities associated with weed control and soil enhancement. GMCCs, particularly for smallholder farmers, are a multi-dimensional issue and would benefit from continuous research to more fully understand their long-term consequences.

## CHAPTER SEVEN

### 7.0 REFERENCES

- Aber, J.D., Mellilo, J.M., McClaugherty, C.A., 1990. Forecasting long-standing arrangements of mass loss, nitrogen dynamics, and soil organic matter formation from primary fine litter chemistry in moderate forest ecosystems. *Canadian Journal of Botany*.
- Abrol, I.P., Gupta, R.K., Malik, R.K., 2005. Conservation agriculture- Standing and predictions. Center for progression of Maintainable Agriculture, New Dehli pp. 242.
- ACDI/VOCA, 2011. Reestablishing economic agricultural maintenances in Zimbabwe (REALIZ)- final report, Restoring Maintenances Annual Programme Statement. USAID, Zimbabwe.
- Aikins, S.H.M., Bart-Plange, A., Opoku-Baffour, S., 2010. Presentation assessment of jab planters for maize planting and chemical fertilizer application. *J. Agric. Biol. Sci.* 5, 5.
- Altieri, M.A., 1999. The environmental role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment* 74, 19–31.
- Anderson, J.M., Ingram, J.S.I., 1998. Humid soil biology and fertility. A manual of methods, 2nd ed. information Press, Eynsham.
- Baijukya, F.P., De Ridder, N., Giller, K.E., 2006. Nitrogen discharge from decomposing residues of leguminous cover crops and their effect on pearl millet yield on exhausted soils of Bukoba District, India. *Plant Soil* 277, 73–95.
- Baijukya, F.P., De Ridder, N., Giller, K.E., 2005. Management of legume cover crops and their residues to improve productivity of exhausted soils in the humid tropics: A case study in Bukoba District, Tanzania. *Nutr. Cycl. Agroecosystems* 34, 56–97.
- Baligar, V.C., Fageria, N.K., 2007. Agronomy and composition of tropical cover crops. *J. Plant Nutrition*. 30, 1287–1339.

Barbour, M. G., Burk, J. H., Gilliam, F. S., & Schwartz, M. W. (2008). Techniques of Sampling the Plant Community. In *Global Plant Ecology* (3rd ed., pp. 110–139). Menlo Park, CA, USA: Addison Wesley Longman, Inc.

Barnard, C., 1969. Herbage plant species, division of plant industry, CSIRO, Canberra. p. 317-349.

Baudron, F., Andersson, J.A., Corbeels, M., Giller, K.E., 2012. Deteriorating Yield? Ploughs, Conservation Agriculture and the Problem of Agricultural Strengthening: An taken from the Zambezi Valley, Zimbabwe. *J. Dev. Stud.* 48, 393–412. Doi:

Bedoussac, L., Justes, E., 2011. A contrast of frequently used guides for assessing species interactions and intercrop efficiency: Application to durum wheat–winter pea intercrops. *Field Crops Res.*

Beuerlein, J., 2001. Extension factsheet: intercropping cropping wheat and soya beans. *Horticulture. Crop Sci.*

Blevins, R.L., Herbek, J.H., Frye, W.W., 1990. Green manure covercover crops as a nitrogen source for no-tillage maize and grain sorghum. *Agron. J.* 82, 769–772.

Boddey, R.M., Bruno, J.R.A., Segundp, U., 2006. Leguminous organic nitrogen fixation in ecological tropical agroecosystems, in: Uphoff, N. (Ed.), *Biological Approaches to Sustainable Soil Systems*. CRC Press, Taylor & Francis Group, pp. 301–308.

Bogdanski, A., 2012. Incorporated food–energy systems for conservation agriculture. *Agric. Food Secur.*

Bonham, C. D. (2003). *Quantities for Land-dwelling Vegetation* (2nd ed.). John Wiley & Sons.

Bonsu, P.O., Asibuo, J.Y., 2013. Rotational Effects Of Legumes On Pearl millet and Maize Yield. *Int. J. Sci. Technol. Res.* 2, 222–227.

Botha, A., 2010. *Common weeds species of agricultural crops and gardens in Southern Africa*, 2nd ed. Agricultural Research Council, South Africa.

- Bowman, A., Scott, B., 2009. Management of ground cover crops in the cropping zone of NSW. Prime Fact 957.
- Brainard, D.C., Bellinder, R.R., Hahn, R.R., Shah, D.A., 2008. Cover crop Rotation, Cover Crop, and Weed Managing Special effects on Weed Seedbanks and Yields in Snap Bean, Sweet Corn, and Cabbage.
- Campbell, J.K., 1990. Dibble sticks, donkeys, and diesel: Machines in crop manufacture. International Rice Research Institute, Manilla, Philippines.
- Chauhan, B. S., Singh, R. G., & Mahajan, G. (2012). Environmentalism and managing of weeds under conventional and conservation agriculture: A review. *Crop Protection*, 33, 47–61.
- Chivinge, O. A. (1988). Weed Study of Arable Lands of Small-Scale Farming units Zimbabwe. *Zambetzia*, 15(2), 167–179. Retrieved from <http://pdfproc.lib.msu.edu/?file=/DMC/AfricanJournals/pdfs/Utafiti/s4NS/aejps004NS008.pdf>.
- Clark, A., 2007. Sunnhemp: *Crotalaria Juncea*. Managing of cover crops cost-effectively: 3rd ed. Sustainable/conservation Agriculture Research and Education, College Park, MD. [http://www.sare.org/Learning-Center/Books?managing-Cover-Crops-Profitably-3rd Edition/Text-Version/Printable-Version](http://www.sare.org/Learning-Center/Books?managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Printable-Version) (accessed 3 September 2018).
- Derpsch, R., 2008. No tillage and conservation agriculture: A Journal report, in: Goddard, T.,
- Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No tillage Farming Systems. World Association of Soil and Water Preservation, Bangkok, p. 409.
- Donovan, G., Casey, F. 2000. Managing Soil fertility in sub-Saharan Africa. 44 Soil World Bank, Washington DC: World Bank Technical Paper.

- Dubreil, N., 2011. Targeting Conservation Agriculture (CA) innovations to reduce soil degradation and food insecurity in semi-arid Africa- Journal review (MSc International Land and Water Management (MIL)). Wageningen University, The Netherlands.
- Dugje, I.Y., Omoigui, L.O., Ekeleme, F., Kamara, A.Y., Ajeigbe, H., 2009. A Farmers' guide towards the production in West Africa. IITA Ib. Niger. 20.
- Duke, J.A., 1983. Handbook of energy crops NewCROP (New Crops Resource Online Program), Purdue Univ. Center for New Crops and Plant Products.
- Dumanski, J., Peiretti, R., Benites, J.R., McGarry, D., Pieri, C., 2006. The paradigm of conservation agriculture, in: World Association of Soil and Water Conservation. pp. 58–64.
- Erenstein, O., 2003. Smallholder conservation farming in the sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems & Environment* 90, 117–137.
- FAO, (2015). Sustain and Grow: A Policymaker's Guide to the Sustainable Strengthening of Smallholder farmers' Crop Production 11–39.
- FAO, 2014. *Canavaliaensiformis* (L.) DC (Jack bean).  
[www.fao.org/ag/agp/AGPC/doc/Gbase/data/pf000012.htm](http://www.fao.org/ag/agp/AGPC/doc/Gbase/data/pf000012.htm) (accessed 01 July 2018).
- FAO, 2013a. Up-date conservation agriculture database in Aqua Stat.  
<http://www.fao.org/ag/ca/6c.html> (accessed 23 July 2017).
- FAO, 2013b. The Li seeder. [http://www.cau.edu.cn/cie/en/aboutus/index\\_cau.htm](http://www.cau.edu.cn/cie/en/aboutus/index_cau.htm) (accessed 14 June 2018).
- FAO, 2012a. The State of Food Insecurity in the World.  
<http://www.fao.org/docrep/016/i3027e/i3027e00.htm> (accessed 11 February 2018).
- FAO, 2012b. Crop prospects and food situations, Global information and early warning systems on food and agriculture. Rome.

FAO, 2012c. Conservation agriculture. <http://www.fao.org/ag/ca/> (accessed 23 May 2018).

FAO, 2010. Green manure/ cover crops and crop rotation in conservation agriculture. [www.fao.org/docrep/014/i2190e/i2190e00.pdf](http://www.fao.org/docrep/014/i2190e/i2190e00.pdf) (accessed 15 March 2018).

FAO, 2009. Global agriculture towards 2050. [www.fao.org/fileadmin/templates/.../HLEF2050\\_Global\\_Agriculture.pdf](http://www.fao.org/fileadmin/templates/.../HLEF2050_Global_Agriculture.pdf) (accessed 18 March 2018). Rome.

FAO, 2006. Crops and cropping systems. [www.fao.org/ag/ca/AfricaTrainingManualCD/.../06CROP1.PDF](http://www.fao.org/ag/ca/AfricaTrainingManualCD/.../06CROP1.PDF) (accessed 14 February 2019).

FAO, 2002. Conservation agriculture: Case study in Latin America and Africa. 78 Rome: FAO Soils Bulletin.

FAO, 2001. The economics of conservation agriculture. <http://www.fao.org/ag/ca> (accessed 12 September 2017).

Fernandez, H.C., Silveira, J., Rinaldi, P.C.N., 2008. Avaliação do custo energético de diferentes operações agrícolas mecanizadas. *Ci. Agrotec* 32, 1582–1587.

Ferreroa, A., Usowicz, B., Lipiec, J., 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. *Soil and Tillage Research* 84, 127–138.

FEWS NET, 2013. FEWS NET. Reduced incomes and high food prices are expected to increase food insecurity among poor households in southwestern districts. ZIMBABWE Food Security Outlook. <http://reliefweb.int/report/zimbabwe/zimbabwe-food-security-outlook-September-2018-March-> 2018 (accessed 28 January 2018).

Gan, Y., Neil Harker, K., Mc Conkey, B., Suleimenov, 2008. Moving towards sustainable agriculture no-till practices in Northern Eurasia, in: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), *No till Farming Systems*. World Association of Soil and Water Conservation, Bangkok, p. 409.

- García-del-Pino, F., & Morton, A. (2017). Synergistic effect of the herbicides glyphosate and MCPA on survival of entomopathogenic nematodes. *Biocontrol Science and Technology*, 20(5), 413–448.
- Gathumbi, S.M., Gadisch, G., Giller, K., 2002. <sup>15</sup>N natural abundance as a tool for assessing Nitrogen-fixation of herbaceous shrub and tree legumes in improved fallows. *Soil Biology and Biochemistry* 34, 900–10611.
- Gentile, R., Vanlauwe, B., van Kessel, C., Six, J., 2009. Managing Nitrogen availability and losses by combining chemical fertilizer-Nitrogen with a number of different quality residues in Kenya. *Agriculture, Ecosystems & Environment* 131, 308–314.
- Gianessi, L., 2009. Solving Africa's problematic weed problems: Increasing crops production and improving the lives of women. Crop Protection Research Institute: CropLife foundation.
- Gianessi, L., Williams, A., 2011. Overseeing the obvious: the opportunity for herbicides in Africa. *Outlooks Pest Management*. 223, 311–318.
- Givens, W.A., David, S.R., Greg, K.R., William, J.G., Bryan, G.Y., Robert, G.W., Michael, D.K.O., David, J., 2009. Journal of tillage tendencies following the acceptance of Glyphosate-resistant crops. *Weed Technology* 123, 140–165.
- Głąb, T., Kulig, B., 2008. Effect of residue cover and tillage system on soil porosity under wheat (*Triticumaestivum*). *Soil Tillage Res.* 99, 169–178.
- Goeb, J., 2013. Conservation agriculture farming Adoption and Impact among First Year Adopters in Central Zambia.
- Gomez, K.A., Gomez, A.A., 1984. *Statistics for agricultural research*, 2nd ed. John Wiley and Sons, New York.
- Gowing, J.W., Palmer, M., 2007. Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. *Soil use and management* 27–67.

- Habte, M., 2006. The roles of arbuscular mycorrhizas in plant and soil health, in: Uphoff, N. (Ed.), *Biological Approaches to Sustainable Soil Systems*. CRC Press, Taylor & Francis Group, pp. 131–147.
- Haney, R. L., Senseman, S. A., Hons, F. M., & Zuberer, D. A. (2000). The Effect of glyphosate on soil microscopic activity and biomass. *Weed Science*, 18, 59–63.
- HanzlikHartwig, N.L., Ammon, H.U., 2002. Cover crops and living mulches. *Weed Sci.* 50, 688–699.
- Herrero, M., Thornton, P.K., Notenbaert, A., Msangi, S., Wood, S., MacMillan, S., Dixon, J., *Sustainable agriculture in Norther Namibia*.
- Bossio, D., van de Steeg, J., Freeman, H.A., Lynam, J., Rao, P.P., Gerard, B., McDermott, J., Sere, C., Peters, M., Rosegrant, M., 2010. Smart investments in sustainable food production: reexamining mixed crop-livestock Farming systems. *Sci* 327, 822–825.
- Heyns., M 1991. climate of Namiba: Evidence of Rain fall patterns in Namibia. <http://www.Namibia.co.na.rainfalldata.php?species id=128060> (accessed 12 September 2018).
- Légère, V., Tran, G., 2013. Jack bean (*Canavaliaensiformis*). Feedipedia.org. A programme by INRA, CIRAD, AFZ and FAO. <http://www.feedipedia.org/node/327> (accessed 01 July 2018).
- Légère, V., Tran, G., Bastianelli, F., Lebas, F., Nozière, P., 2013a. Cowpea (*Vignaunguiculata*) forage. Feedipedia.org. A programme by INRA, CIRAD, AFZ and FAO. <http://www.feedipedia.org/node/233> (accessed 29 September 2018).
- Légère, V., Tran, G., Baumont, R., 2013b. Common vetch (*Vicia sativa*). Feedipedia.org. A programme by INRA, CIRAD, AFZ and FAO. <http://www.feedipedia.org/node/239> (accessed 25 July 2018).
- Ingestad, T., Agren, G.I., 1995. Plant nutrition and growth: Basic principles. *Plant Soil* 168-169, 15–20.

Jaleta, M., Kassie, M., Shiferaw, B., 2012. Trade-offs in crop residue utilization in mixed crop-livestock systems and implications for conservation agriculture and sustainable land management, in: International Association of Agricultural Economists (IAAE) Triennial Conference. Foz do Iguacu, Brazil.

Jat, M.L., Singh, R.G., Sidhu, H.S., Malik, R.K., Kamboj, B.R., Jat, R.K., Singh, V.P., Patil, S.G., Raj, G., 2010. Resource conserving technologies in South Asia: Frequently asked questions. Technical Bulletin. 44 New Dehli, India: International Maize and Wheat Improvement Center.

Jones, J., MacRobert, A.L., Chandiramani, M., 2010. The importance of legumes in cereal cropping systems. Technical Extension Bulletin, IRRI- Los Banos, Phillipines.

Karberg, N.J., Scott, N.A., Giardina, C.P., 2008. Methods for estimating decomposition of green manure cover crops, in: Hoover, M.C. (Ed.), Field Measurements of Forest Carbon Monitoring. Springer Science + Business Media B. V.

Kassam, A., Friedrich, T., 2011. Conservation agriculture: principles of conservation agriculture, ecological land management and ecosystem services, in: Proceedings of the 40th National Convention of the Italian Agronomy Society, Teramo, Italy.

Kassam, A., Friedrich, T., 2009. Managing inputs (Water, Nutrients, Seed and Agrochemicals), in: Plenary Session. Presented at the IV<sup>th</sup> World Congress on sustainable Agriculture, New Dehli, p. 85.

Kessler, C.D.J., 1990. An agro ecological evaluation of jack bean (*Canavalia ensiformis*) in Yucatan, Mexico. I. Plant Density. *Exp. Agric.* 26, 11–22.

Kjeldahl, J.Z., 1883. New methods of the determination of nitrogen in organic bodies. *Anal. Chem.* 122, 164.

Kladviko, E., 2011. The significance of Cover crops for modern cropping systems <http://www.ag.purdue.edu/agry/extension/Documents/CoverCropsOverview.pdf> (accessed 08 August 2018).

Kline, R., 2000. Approximating cover crop residue for the soil erosion control. Soil Fact Sheet 141, 320–521.

Kriauciuniene, Z., Velicka, R., Raudonius, S., 2012. The influence of crop mulch retention on their rate of decomposition in the soil: a litterbag study. *Agriculture* 139, 170–290.

Kurlovich, B.S., Stankevich, A.K., 2002. The classification of Lupins, in: *Lupins: Geography, Arrangement, Genetic Resources and Breeding*. Department of Leguminous Crops of N. I. Vavilov Institute of Plant Industry, pp. 39–87.

Kaurivi, J. Z. U., Meroro, A., Mudamburi B., & Namalambo, E. (2010). Sustainable agriculture in Northern Namibia: documentation and combination. Conservation Agriculture (CA) documentation for Namibia commissioned by FAO March to September 2010.

Kuvare, U, Maharero, T and Kamupingene, G (2008) Farming Systems research on the Change to Allow the Adaptation to Climate Change. Embark on for the Ministry of Environment and Tourism and the United Nations Development Program Namibia, ground work for Namibia's Second National Communication to the United Nations Framework Agreement on Climate Change.

Légère, A., Samson, N., Rioux, R., 1993. Perennial weeds in conservation agriculture systems: more common than conventional tillage systems? Offered at the Brighton Crop Protection Conference-Weeds (1993): Proc, British Crop Protection Council, Farnham, Great Britain, pp. 847–852.

Lee, N., & Thierfelder, C. (2017). Weed control strategies under conservation agriculture in dryland smallholder farming units of Northern Namibia. A review. *Agriculture for Sustainable Development*, 38(44).

Lesoing, G., Moomaw, R., Francis, C., 1991. Two crops in a single year: Intercropping. *Hist. Mater. Univ. Neb.-Linc. Ext.* 22.

Liebman, M., Dyck, E., 1993. Crop rotation and relay cropping strategies for weed management. *Ecol. Appl.* 92–122.

Lu, Y., Watkins, K.B., Teasdale, J.R., Abdul-baki, A.A., 2000. Lu, Y., Watkins, K. B., Teasdale, J. R. and Abdul-baki, A. A. Green manure over crops in ecological food production. *Food Rev. Int.* 116, 121–157.

- Maasdorp, B., & Titterton, M., 1997. Nourishing enhancement of pearl millet and maize silage for Dairying: Mixed crop silages from sole and intercropped leguminous cover crops and a long season variety of maize. 1. Biomass yield and nutritive value. *Anim. Feed Sci. Technol.* 241–261.
- Makanganise, A., & Mabasa, S., 1999. Identifying of essential weeds of arable lands in Zimbabwe. Department of Research and Specialist Services, Harare, Zimbabwe.
- Makwara, E.C., 2010. Sustainable and Lucrative Farming systems through Conservation Agriculture in Zimbabwe: Projections, Opportunities and Restraints. *J. Sustain. Dev. Afr.* 12, 180–190.
- Mall, U., Singh, G.S., 2014. Soil seed bank dynamics: History and agro-ecological significance in sustainability of different agro-ecosystems, in: Fulekar, M.H., Pathak, B., Kale, R.K. (Eds.), *Environment and Sustainable Development*. Springer Science + Business Media B. V, New Dehli, pp. 28–46.
- Mandumbu, R., Jowa, P., Karavina, C., Tibugari, H., 2011. Incorporating weed management in Zimbabwe's smallholder sector, where are we?: A review. *Modern Applied Sciences* 5, 111–117.
- Mangosho, E., & Mupambwa, H. A. (2013). *Integrated Weed Management and Control in Selected Field Crops: A Manual for Extension workers, Trainers, Farm Managers and Researchers*. Harare, Zimbabwe.
- Mapfumo, P., Campbell, B.M., Mpeperekwi, S., 2001. Leguminous cover crops in soil fertility management: A case study of pigeon pea in smallholder farming systems in Zimbabwe, 329–414.
- Mapfumo, P., Mtambanengwe, F., Vanlauwe, B., 2007. Organic matter quality and management effects on enhancement of soil biological matter fractions in contrasting soils of Zimbabwe. *Plant Soil* 296, 137–150.

Mashavave, T.C., 2003. Economics of chemical fertilizer use for maize production by smallholder farmers in the drought susceptible to areas of Zimbabwe: the case of Shurugwi ward 5- Mfiri, Zimbabwe.

Mashingaidze, A.B., 2004. Educating farmers on weed management and crop productivity in maize systems in Zimbabwe (PhD). Wageningen University, The Netherlands.

Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J., Hove, L., 2012. Crop production (yield) and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil Tillage Res.* 124, 102–110. doi:10.1016/j.still.2012.05.008

Mashingaidze, N., Madakadze, I.C., Twomlow, S.J., 2012. Response of weed flora to conservation agriculture systems and weeding intensity in semi-arid Zimbabwe. *African J. Agric.*

Mazvimavi, K., Nyathi, P., Murendo, C., 2011. Conservation agriculture systems and their challenges in Zimbabwe. Presented at the 5th World Congress of Conservation Agriculture Incorporated 3<sup>rd</sup> farming systems Design Conference, Brisbane, Australia.

McDonagh, J.F. and Hillyer, A.E.M. (2003). Grain legumes in pearl millet system in northern Namibia: An assessment of potential nitrogen contributions. *Experimental Agriculture.* 39. 349-362.

McCarthy, J.R., Pfoest, D.L., Currence, D.H., 1993. Conservation tillage and residue management to reduce soil erosion. University of Missouri.

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. doi:10.1016/j.cropro.2014.11.010.

Mhlanga, B., Cheesman, S., Maasdorp, B., Mupangwa, W., Thierfelder, C., 2015b. Contribution of cover crops to the productivity of maize-based conservation agriculture systems in Zimbabwe. *Crop Sci.* Forthcom.

Mhlanga, B., Cheesman, S., Maasdorp, B., & Mupangwa, W. (2017). Relay intercropping and mineral fertilizer effects on biomass production, maize productivity and weed dynamics in contrasting soils under conservation agriculture. *Journal of Agricultural Science*, 155, 876– 887. <https://doi.org/10.1017/S0021859616000927>.

MoHSS, (2014). Surveillance Report of the 2014, National HIV Sentinel Survey. Directorate of Special Programmes Response Monitoring & Evaluation Subdivision. Windhoek. Namibia.

MoHSS, (2008). Surveillance Report of the 2008, National HIV Sentinel Survey. Directorate of Special Programmes Response Monitoring & Evaluation Subdivision. Windhoek. Namibia.

Morris, M.L., 2007. Fertilizer use in African agriculture: Lessons learned and good practice guidelines. World Bank Publications.

Mueller, M. A. N. (2007). *Grasses of Namibia*. Windhoek, Namibia: Ministry of Agriculture, Water, and Forestry.

Muldoon, D.K., 1985. Summer legume forage crops: cowpeas, lablab, soybeans. *Aust. J. Exp. Agric.* 25, 417–423.

Mullen, C., 1999. Summer legume forage crops: cowpeas, lablab, soybeans. NSW Department of Primary Industries. Broadacre crops. Agfact P4.2.16.

Muoni, T., Rusinamhodzi, L., Thierfelder, C., 2013. Weed control in conservation agriculture systems of Zimbabwe: Identifying economical best strategies. *Crop Prot.* 53, 23–28. doi:10.1016/j.cropro.2013.06.002.

Mupangwa, W., Twomlow, S., 2000. Socioeconomics and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe 101, 20–29.

Mureithi, J.G., Gachene, C.K.K., Ojiem, J., 2003. The role of green manure legumes in smallholder farming systems in Kenya: the legume research network project.

Muringai, V., Mano, R., Rugube, L., Foti, R., Mutenje, M., Mahaka, H.T., 2008. The Competitiveness and Comparative Advantage of Zimbabwe's Fertilizer Industry in Producing Compound and Phosphate Fertilizers.

Mutema, M., Mafongoya, P.L., Nyagumbo, I., Chikukura, L., 2013. Effects of crop residue and reduced tillage on macro fauna abundance. *Journal of Organic Systems* 1.

Muza, L., Dhliwayo, H.H., Twomlow, S.J., 1996. Dryland maize response to different combinations of tillage and weeding methods, in: CIMMYT Maize Program. Presented at the Fifth Eastern and Southern Africa Regional Maize Conference, CIMMYT, Arusha, Tanzania, pp. 110–114.

Mwangi, H. W., Kihurani, A. W., Wesonga, J. M., Ariga, E. S., & Kanampiu, F. (2015). Effect of Lablab purpureus L. cover crop and imidazolinone resistant (IR) maize on weeds in drought prone areas, Kenya. *Crop Protection*, 72, 36–40. <https://doi.org/10.1016/j.cropro.2015.02.013>.

Namibia Crop Prospects, Food Security and Drought Situation Report, June, 2010. Namibia Early Warning and Food Information Unit (NEWFIS), Ministry of Agriculture, Water and Forestry, Namibia.

Naeem, M., Masroor, M., Khan, A., Moinuddin, M., Siddiqui, H., 2009. Triacntanol stimulates nitrogen-fixation, enzyme activities, photosynthesis, crop productivity and quality of hyacinth bean (*Lablab purpureus* L.). *Sci. Hortic.* 121, 389–396.

Nakamoto, T., Yamagishi, J., Miura, F., 2006. Effects of reduced tillage on weeds and soil organisms in winter wheat and summer maize cropping on Humic Andosols in Central Japan. *Soil and Tillage Research* 94–106.

Namibia Early Warning and Food Information Unit (NEWFIS), 1993. Namibia Crop Prospects and Food Security Situation Report. IN Jodhim, N. (Ed.) Windhoek.

NSA, 2014. Namibia Household Income & Expenditure Survey (Nhies) 20010/2012. IN NSA (Ed.) Windhoek, Namibia Statistics Agency.

- NSA, 2015. The Namibia Agricultural Census of 2013/2014. Communal Sector Report. November 2015.
- Ngwira, A.R., Thierfelder, C., Lambert, D.M., 2012. Conservation agriculture systems for Malawian smallholder farmers: long term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 1–14.
- Nolan, K.A., Callahan, J.E., 2006. Beachcomber biology: the Shannon-Weiner species diversity index, in: Proc. Workshop ABLE. pp. 334–338.
- Nyagumbo, I., 1999. Conservation tillage for sustainable crop production systems: Experiences from on-station and on-farm research in Zimbabwe, in: Kaumbutho, P.G., Simalenga, T.E. (Eds.), *Conservation Tillage with Animal Traction*. Presented at the A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESSA), p. 173.
- Nyamapfene, K.W., 1999. *The soils of Zimbabwe*. Nehanda Publishers (Pvt) Ltd, Harare, Zimbabwe.
- Nyanga, P.H., Johnsen, F.H., akon, Kalinda, T.H., 2012. Gendered impacts of conservation agriculture and paradox of herbicide use among smallholder farmers.
- Okito, A., Alves, B.J.R., Urquiaga, S., Boddey, R.M., 2004. Nitrogen fixation by groundnut and velvet bean and residual benefit to a subsequent maize crop. *Pesqui. Agropecuária Bras.* 39, 1183–1190.
- Oliveira, A.E.A., Gomes, V.M., Sales, M.P., Fernandes, K.V.S., Carlini, C.R., Xavier-Filho, J., 1999. The toxicity of jack bean [*Canavalia ensiformis* (L.) DC.] canatoxin to plant pathogenic fungi. *Rev. Bras. Biol.* 59, 59–62.
- Olofsson, J., Oksanen, L., 2000. Role of litter decomposition for the increased primary production in areas heavily grazed by reindeer. *Oikos* 507–515.

- Olorunmaiye, P.M., 2010. Weed control potential of five legume cover crops in maize/cassava intercrop in a Southern Guinea savanna ecosystem of Nigeria. *Aust. J. Crop Sci.* 4.
- PACE, 2011. *Tephrosia vogelii*. [www.worldagroforestry.org](http://www.worldagroforestry.org) (accessed 03 September 2013).
- Peachey, R.E., Luna, J., Dick, R., Sattell, R., 1999. Cover crop weed suppression in annual rotations. Oregon State University Extension Service.
- Pohill, R.M., 1982. *Crotalaria* in Africa and Madagascar. A. A Balkema, Rotterdam, 389 pp.
- Rahnama, A., Latifian, M., 2013. Intercropping relative efficiency and its effects on date palm pests and disease control. *Int. J. Agric. Res. Rev.* 3, 617–623.
- Ratnadass, A., Fernandes, P., Avelino, J., Habib, R., 2012. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agron. Sustain. Dev.* 32, 273–303. doi:10.1007/s13593-011-0022-4
- Reddell, P., Bowen, G.D., Robson, A.D., 1985. The effects of soil temperature on plant growth, nodulation and nitrogen fixation in *Casuarina cunninghamiana* Miq. *New Phytologist* 101, 441–450.
- Reganold, J.P., Glover, J.D., Andrews, P.K., Hinman, H.R., 2001. Sustainability of three apple production systems. *Nature* 410, 926–929.
- Reicosky M.R., 2015. Conservation agriculture practises and challenges in Zimbabwe. Presented at the 5th World Congress of Conservation Agriculture Incorporating 3rd farming systems Design Conference, Brisbane, Australia.
- Roodt, V. (1998b). *Trees & Shrubs of the Okavango Delta: Medicinal Uses and Nutritional Value*. Gaborone: Shell Oil Botswana.
- Rusinamhodzi, L., Corbeels, M., Nyamangara, J., Giller, K.E., 2014. Maize-grain legume intercropping is an attractive option for ecological intensification that reduces

climatic risk for smallholder farmers in central Mozambique. *Field Crops Res.* 136, 12–22.

Rutunga, V., Karanja, N.K., Gachene, C.K.K., Palm, C., 1999. Biomass production and nutrient accumulation by *Tephrosia vogelii* (Hemsley) A. Gray and *Tithonia diversifolia* Hook F. fallows during the six-month growth period at Maseno, West Kenya. *Biotechnol. Agron. Soc* 3, 237–246.

Samba, R.T., Sylla, S.N., Neyra, 2002. Biological nitrogen fixation in *Crotalaria* species estimated using the <sup>15</sup>N isotope dilution method.

Schippers, R.R., 2004. *Crotalaria ochroleuca* G. Don In: Grubben, G. J. H & Denton, O. A (Editor). *PROTA 2: Vegetables/ Legumes*. [CD Rom]. PROTA, Wageningen, The Netherlands.

Schomberg, H.H., Steiner, J.L., Evett, S.R., Moulin, A.P., 1996. Climatic influence on residue decomposition prediction in the Wind Erosion Prediction System. *Theor. Appl. Climatol.* 54, 5–16. doi:10.1007/BF00863554

Schomberg, H.H., Steiner, J.L., Unger, P.W., 1994. Decomposition and nitrogen dynamics of crop residues: Residue quality and water effects. *Soil Sci Soc Am* 372–382.

Scoones, I., Marongwe, N., Mavedzenge, B., Murimbarimba, F., Mahenehene, J., Sukume, C., 2011. *Zimbabwe's land reform: A summary of findings*. IDS: Brighton.

Sheahan, C.M., 2012. *Plant guide for lablab (Lablab purpureus)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ. 08210.

Shetto, R.M., 1999. Indigenous soil conservation tillage systems and risks of animal traction on land degradation in Eastern and Southern Africa, in: *Animal Traction Network for Eastern and Southern Africa (ATNESA)*. Harare, Zimbabwe.

Sims, B.G., Thierfelder, C., Kienzle, J., Friedrich, T., Kassam, A., 2012. Development of the conservation agriculture equipment industry in sub-Saharan Africa. *Appl. Eng. Agric.* 28, 813–823.

- Skinner, E.M., Diaz-Perez, J.C., Phatak, S.C., Schomberg, H.H., Vencill, W., 2012. Allelopathic effects of sunnhemp (*Crotalaria juncea* L.) on germination of vegetables and weeds. *Horticultural Science* 47, 138–142.
- Sommer, R., Bossio, D., Desta, L., Dimes, J., Kihara, J., Koala, S., Mango, N., Rodriguez, D., Thierfelder, C., Winowiecki, L., 2013. Profitable and Sustainable Nutrient Management Systems for East and Southern African Smallholder Farming Systems—Challenges and Opportunities.
- Spandl, E., Durgan, B.R., Forcella, F., 1999. Foxtail (*Setaria* spp.) seedling dynamics in spring wheat (*Triticum aestivum*) are influenced by seeding date and tillage regime. *Weed Science* 156–160.
- Spellerberg, I. F., & Fedor, P. J. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the ‘Shannon–Wiener’ Index. *Global Ecology & Biogeography*, 12, 177–179.
- Statistix, 2008. Statistix 9: analytical software. [www.statistix.com](http://www.statistix.com). Tallahassee, USA.
- Stevenson, F.C., Légère, A., Simard, R.R., Angers, D.A., Pageau, D., Lafond, J., 1997. Weed species diversity in spring barley varies with crop rotation and tillage, but not with nutrient source. *Weed Sci.* 45, 798–806.
- Sullivan, D.M., Datta, R., Andrews, N., Pool, K.E., 2011. Predicting Plant-available nitrogen release from cover crop residues. [http://smallfarms.oregonstate.edu/sites/default/files/WNMC11\\_Sullivan\\_p55.pdf](http://smallfarms.oregonstate.edu/sites/default/files/WNMC11_Sullivan_p55.pdf) (accessed 02 February 2014).
- Tan, N., Fung, S., Sim, S., Marinello, E., Guerranti, R., Aguiyi, J., 2009. The protective effect of *Mucunapruriens* seeds against snake venom poisoning. *Journal of Ethnopharmacology* 123, 356–358.
- Taylor, L., County, T., 2012. Velvet bean (*Mucunapruriens*). <http://www.rain-tree.com/velvetbean.htm#UzFY4oXQEUM> (accessed 25 March, 2014). Teasdale, J.R., 1999. Contribution of Cover Crop Mulches to Weed Management. Presented at the New

England Vegetable and Berry Growers Conference and Trade Show, College of Agriculture and Natural Resources, Sturbridge, pp. 347–350.

Teasdale, J.R., 1998. Cover crops, smother plants, and weed management, in: Hatfield, J.L., Buhler, D.D., Stewart (Eds.), *Integrated Weed and Soil Management*. Ann Arbor Press, Chelsea, MI, pp. 247–270.

Teasdale, J.R., Brandsæter, L.O., Calegari, A., SkoraNeto, F., 2007a. Cover crops and weed management, in: *Non Chemical Weed Management*. CAB International.

Teasdale, J.R., Mohler, C.L., 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. *Agron. J.* 85, 673–680.

The United States Agency for International Development (USAID), 2004. *Conservation Agriculture Program for Northern Namibia to Help Mitigate Drought Disasters. Program Description*. Washington, National Cooperative Business Association's CLUSA International Program.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L., 2013. Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. *Int. J. Agric. Sustain.* 11, 108–124. doi:10.1080/14735903.2012.703894

Thierfelder, C., Wall, P.C., 2008. *Conservation agriculture- a sustainable system. Technical extension bulletin, CIMMYT- Southern Africa*.

Thierfelder, C., Wall, P.C., 2010. Rotations in conservation agriculture systems of Zambia: Effects on soil quality and water relations. *Experimental Agriculture* 46, 1–7.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L., 2013. Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. *Int. J. Agric. Sustain.* 11, 108–124. doi:10.1080/14735903.2012.703894

Tittonell, P., Scopel, E., Andrieu, N., Posthumus, H., Mapfumo, P., Corbeels, M., van Halsema, G.E., Lahmar, R., Lugandu, S., Rakotoarisoa, J., Mtambanengwe, F., Pound, B., Chikowo, R., Naudin, K., Triomphe, B., Mkomwa, S., 2012. *Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil*

degradation and food insecurity in semi-arid Africa. *Conserv. Agric. Dry Areas* 132, 168–174. doi:10.1016/j.fcr.2011.12.011

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.

Uchida, R.S., 2000. Essential nutrients for plant growth: nutrient functions and deficiency symptoms. *Plant Nutr. Manag. Hawaii’s Soils* 31–55.

Ulber, L., Steinmann, H.-H., Klimek, S., Isselstein, J., 2009. An on-farm approach to investigate the impact of diversified crop rotations on weed species richness and composition in winter wheat. *Weed Res.* 49, 534–543. doi:10.1111/j.1365-3180.2009.00722.x

Undersander, D.J., Ehlke, N.J., Kaminski, A.R., Doll, J.D., Kelling, K.A., 2014. Hairy vetch. *Alternative Crops Manual*. University of Wisconsin-Extension.

USDA-NRCS, 2012. Sunn hemp (*Crotalaria juncea* L.) release brochure. Cape May Plant Materials Center, Cape May, NJ. <http://plant-materials.ncrs.usda.gov> (accessed 4 September 2013).

Valenzuela, H., Smith, J., 2002. Sustainable agriculture green manure crops. SA-GM-7. Cooperative Extension Service, College of Tropical Agric. and Human Resources, Uni. of Hawaii at Manoa. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/lablab.pdf> (accessed 02 February 2013).

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., Nolte, C., 2014. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Res.* 155, 10–13. doi:10.1016/j.fcr.2013.10.002

Van Saun, R.J., 2006. Determining forage quality: Understanding feed analysis. *Lamalink.com* 3, 18–19, 22, 24, 25–26.

- Verhallen, A., 2001. Cover Crops: Hairy vetch.  
[www.omafra.gov.on.ca/english/crops/facts/cover.../hairyvetch.htm](http://www.omafra.gov.on.ca/english/crops/facts/cover.../hairyvetch.htm) (accessed 18 September 2014).
- Vigil, M.F., Kissel, D.E., 1991. Equations for estimating the amount of nitrogen mineralized from crop residues. *Soil Sci. Soc. Am. J.* 64, 918–926.
- Vincent, V., Thomas, R.G., 1960. An agricultural survey of Southern Rhodesia: Part I, in: *The Agroecological Survey*. The Government Printer, Salisbury, p. 345.
- Vogel, H., 1994. Weed in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research* 169–185.
- VSN International, 2002. *GenStat for Windows 14th Edition*. VSN International, Hemel Hempstead, UK. Web page: [GenStat.co.uk](http://GenStat.co.uk).
- Vulnerability Assessment Committee (VAC), 2011. Study to Inform the Design of an Agricultural Dry Land Productivity Project in the Northern Communal Areas of Namibia. Version 2. Final Report. February 2011. Framework Contract Europe Aid/127054/C/SER/Multi. Lot 1: Rural Development. Letter of Contract N°: 2010/250827 –CardnoAgrisystems Consortium comprising: Cardno Emerging Markets (UK) Ltd in association with Agri-Livestock Consultants Ltd, CABI, ECA International S.A.U., MegapescaLda, Quality Institute and Sogreah Consultants SAS.
- Walker, R.L., Burns, I.G., Moorby, J., 2001. Responses of plant growth rate to nitrogen supply: a comparison of relative addition and N interruption treatments. *J. Exp. Bot.* 52, 309–317.
- Wall, P.C., 2007. Tailoring Conservation Agriculture to the Needs of Small Farmers in Developing Countries: An Analysis of Issues. *J. Crop. Improve* 19, 137–155.
- Went, F.W., 1953. The effect of temperature on plant growth. *Annu. Rev. Plant Physiol.* 4, 347–362.
- Whitlow, R., 1987. A national soil erosion survey for Zimbabwe. *J. Soil Water Conserv.* 42, 239–242.

Whittaker, R.H., 1965. Dominance and diversity in land plant communities: Numerical relations of species express the importance of competition in community function and evolution. *Science* 147, 250–260. doi:10.1126/science.147.3655.250

Woomer, P.L., Lan'gat, M., Tungani, J.O., 2004. Innovative maize-legume intercropping results in above- and below- ground competitive advantages for understorey legumes. *West African Journal of Applied Ecology* 85–94.

Wortman, S.E., 2012. Diversification of organic cropping systems with cover crop mixtures: Influence on weed communities, soil microbial community structure, soil moisture and nitrogen, and crop yield (Doctor of Philosophy). University of Nebraska, Lincoln.

Zhang, J., Zheng, L., Jäck, O., Yan, D., Zhang, Z., Gerhards, R., & Ni, H. (2013). Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (*Zea mays* L.) fields in North China Plain. *Crop Protection*, 52, 26–32. <https://doi.org/10.1016/j.cropro.2013.05.001>

ZCATF, 2009. Farming for the future. A guide to conservation agriculture in Zimbabwe, 2nd ed.

## **LIST OF APPENDICES**

### **Appendix 1: Analysis of variance for total weed density at MITC in season 1 (Experiment 1)**

Source DF SS MS F P  
Replicate 2 9499.5 4749.73  
Rotation 9 60154.1 6683.79 2.66 0.0371  
Error 18 45273.9 2515.21  
Total 29  
Note: SS are marginal (type III) sums of squares  
Grand Mean 129.87 CV 38.62

### **Appendix 2: Analysis of variance for total weed density at MITC in season 2 (Experiment 1)**

Source DF SS MS F P  
Replicate 2 13464.3 7752.13  
Rotation 9 20798.5 2310.970.860.0461  
Error 18 50669.1 2814.96  
Total 29  
Note: SS are marginal (type III) sums of squares  
Grand Mean 150.73 CV 35.20

### **Appendix 3: Analysis of variance for total weed density at LRS in season 1 (Experiment 1)**

Source DF SS MS F P  
Replicate 2 1743.2 924.68  
Rotation 9 58450.1 6050.062.580.0453  
Error 18 52655.5 2369.85  
Total 29  
Note: SS are marginal (type III) sums of squares  
Grand Mean 130.80 CV 37.22

**Appendix 4: Analysis of variance for total weed density at LRS in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 19448.3 9724.13

Rotation 9 22694.5 2521.61 1.67 0.0176

Error 18 27207.1 1511.50

Total 29

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

Grand Mean 112.07 CV 34.69

**Appendix 5: Analysis of variance for total weed biomass at MITC in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 589.4 269.900

Rotation 9 6554.2 706.9080.870.5739

Error 18 15476.2 842.654

Total 29

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

Grand Mean 91.240 CV 31.81

**Appendix 6: Analysis of variance for total weed biomass at MITC in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 1622.4 87.417

Rotation 9 6752.0 684.556 0.89 0.4731

Error 18 12448.2 681.512

Total 29

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

Grand Mean 51.573 CV 50.99

**Appendix 7: Analysis of variance for total weed biomass at LRS in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 35784.817997.8

Rotation 9 9319.7 1025.40.420.8133

Error 18 45213.7 2511.9

Total 29

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

Grand Mean 130.23 CV 38.48

**Appendix 8: Analysis of variance for total weed biomass at LRS in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 7660.0 3989.99

Rotation 9 17720.2 1990.03 1.80 0.1788

Error 18 16791.8 1099.58

Total 29

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

Grand Mean 73.553 CV 45.08

**Appendix 9: Analysis of variance for weed species diversity at MITC in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.11198 0.05599

Rotation 9 0.63003 0.07000 0.36 0.0452

Error 18 3.52979 0.19610

Total 29

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

Grand Mean 1.3015 CV 34.03

**Appendix 10: Analysis of variance for weed species diversity at MITC in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.49142 0.24571

Rotation 9 1.84038 0.20449 1.32 0.2230

Error 18 2.60047 0.14447

Total 29

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

Grand Mean 1.8036 CV 21.07

**Appendix 11: Analysis of variance for weed species diversity at LRS in season 1  
(Experiment 1)**

Source DF SS MSF P

Replicate 2 0.105760.05488

Rotation 9 1.28305 0.15256 1.69 0.1312

Error 18 1.43742 0.07976

Total 29

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

Grand Mean 1.0599 CV 26.66

**Appendix 12: Analysis of variance for weed diversity at LRS in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.12685 0.06542

Rotation 9 0.58074 0.06853 0.91 0.5488

Error 18 1.27670 0.07893

Total 29

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

Grand Mean 1.3417 CV 19.85

**Appendix 13: Analysis of variance for weed species evenness at MITC in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.00854 0.00327

Rotation 9 0.04920 0.00547 0.61 0.7833

Error 18 0.16137 0.00697

Total 29

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

Grand Mean 0.2741 CV 34.54

**Appendix 14: Analysis of variance for weed species evenness at MITC in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.04828 0.02414

Rotation 9 0.05085 0.0665 0.470.7765

Error 18 0.21007 0.01167

Total 29

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

Grand Mean 0.4052 CV 26.66

**Appendix 15: Analysis of variance for weed species evenness at LRS in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.00861 0.00430

Rotation 9 0.10160 0.01129 1.58 0.1349

Error 18 0.12100 0.00672

Total 29

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

Grand Mean 0.2348 CV 34.92

**Appendix 16: Analysis of variance for weed species evenness at LRS in season 2  
(Experiment 1)**

Source DF SS MS FP

Replicate 2 0.01780 0.00890

Rotation 9 0.04721 0.00525 1.12 0.3987

Error 18 0.08440 0.00469

Total 29

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

Grand Mean 0.2882 CV 23.76

**Appendix 17: Analysis of variance for weed species richness at MITC in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 2.4667 1.23333

Rotation 9 35.2000 3.91111 0.84 0.5933

Error 18 84.2000 4.67778

Total 29

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

Grand Mean 8.0667 CV 26.81

**Appendix 18: Analysis of variance for weed species richness at MITC in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 7.200 3.6000

Rotation 9 177.867 19.7640 5.240.0004

Error 18 68.133 3.7852

Total 29

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

Grand Mean 9.6000 CV 20.27

**Appendix 19: Analysis of variance for weed species richness at LRS in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 0.4667 0.23333

Rotation 9 1.6333 0.18148 0.14 0.8774

Error 18 22.8667 1.27037

Total 29

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

Grand Mean 4.6333 CV 24.33

**Appendix 20: Analysis of variance for weed species richness at LRS in season 2  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 4.8667 2.43333

Rotation 9 9.6333 1.07037 0.94 0.5349

Error 18 20.4667 1.13704

Total 29

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

Grand Mean 6.6333 CV 16.08

**Appendix 21: Analysis of variance for GMCC grain yield at MITC in season 1  
(Experiment 1)**

Source DF SS MS F P

Replicate 2 351807 175904

Rotation 9 4.4994998948 39.98 0.0000

Error 18 2250473 125026

Total 29

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

Grand Mean 1334.8 CV 26.49

**Appendix 22: Analysis of variance for grain yield at LRS in season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	535762	267881		
Rotation	8		1.988E	2485404	21.69 0.0000
Error	16	1833434	114590		
Total	26				

Note: SS are marginal (type III) sums of squares  
Grand Mean 1000.2 CV 33.84

**Appendix 23: Analysis of variance for GMCC biomass yield at MITC in season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	2.516	1.258		
Rotation	9		3.781	4.2019.83	0.0000
Error	18	7.6914272793			
Total	29				

Note: SS are marginal (type III) sums of squares  
Grand Mean 3760.2 CV 54.97

**Appendix 24: Analysis of variance for GMCC biomass yield at LRS in season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	3658478	1829239		
Rotation	8	4.339	5.424E	36.95	0.0000
Error	16	2.348	1467812		
Total	26				

Note: SS are marginal (type III) sums of squares  
Grand Mean 4059.3 CV 29.85

**Appendix 25: Analysis of variance for PAN at MITC in season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 4370.8 2185.40

Rotation 9 40456.3 4495.14 5.28 0.0013

Error 18 15310.4 850.58

Total 29

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

Grand Mean 34.521 CV 84.48

**Appendix 26: Analysis of variance for PAN at LRS in season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 700.4 350.2

Rotation 8 94452.3 11806.5 50.10 0.0000

Error 16 3770.8 235.7

Total 26

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

Grand Mean 48.070 CV 31.94

**Appendix 27: Analysis of variance for pearl millet grain yield at MITC in season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 1.362 6810467

Rotation 9 1.951 2168272 2.95 0.0244

Error 18 1.324 735768

Total 29

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

Grand Mean 4188.4 CV 20.48

**Appendix 28: Analysis of variance for maize grain yield at LRS in season 2  
(Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	3466590	1733295		
Rotation	9	2.233	2480776	1.66	0.1724
Error	18	2.692	1495711		
Total	29				

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

Grand Mean 4534.5 CV 26.97

**Appendix 29: Analysis of variance for pearl milletstover yield at MITC in season 2  
(Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	7005519	3502759		
Rotation	9	1.312	1458012	2.23	0.0702
Error	18	1.175	652982		
Total	29				

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

Grand Mean 4359.7 CV 18.54

**Appendix 30: Analysis of variance for maize stover yield at LRS in season 2  
(Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	893329	446664		
Rotation	9	7926494	880722	1.79	0.1393
Error	18	8837912	490995		
Total	29				

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

Grand Mean 3155.2 CV 22.21

**Appendix 31: Analysis of variance for supplementary biomass quantity at MITC at end of season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	1.125	5625016		
Rotation	9	1.694	1.882	10.26	0.0000
Error	18	3.301	1834000		
Total	29				

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

Grand Mean 2517.6 CV 53.79

**Appendix 32: Analysis of variance for supplementary biomass quantity at LRS at end of season 2 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	2168045	1084022		
Rotation	9	1.401	1556768	4.53	0.0031
Error	18	6191422	343968		
Total	29				

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

Grand Mean 2066.8 CV 28.38

**Appendix 33: Analysis of variance for supplementary biomass quantity at MITC at end of season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	1527027	763514		
Rotation	9	1.984	2.205	37.50	0.0000
Error	18	1.058	587840		
Total	29				

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

Grand Mean 2337.1 CV 32.81

**Appendix 34: Analysis of variance for supplementary biomass quantity at LRS at end of season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 161645 80822

Rotation 9 3597103 399678 3.84 0.0073

Error 18 1872510 104028

Total 29

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

Grand Mean 760.72 CV 42.40

**Appendix 35: Analysis of variance for percentage contact ground cover at MITC in March of season 1 (Experiment 1)**

Source DF SS MS F P

Replicate 2 3220.47 1610.23

Rotation 9 5748.97 638.77 2.44 0.0511

Error 18 4707.53 261.53

Total 29

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

Grand Mean 71.367 CV 22.66

**Appendix 36: Analysis of variance for percentage contact ground cover at MITC in March of season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 50.87 25.433

Rotation 9 5959.50 662.167 12.76 0.0000

Error 18 933.80 51.878

Total 29

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

Grand Mean 61.833 CV 11.65

**Appendix 37: Analysis of variance for percentage contact ground cover at MITC in June of season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	696.2	348.10		
Rotation	9	10316.5	1146.28	10.55	0.0000
Error	18	1956.5	108.69		
Total	29				

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

Grand Mean 65.600 CV 15.89

**Appendix 38: Analysis of variance for percentage contact ground cover at MITC in June of season 2 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	132.200	66.1000		
Rotation	9	231.200	25.6889	1.06	0.4342
Error	18	435.800	24.2111		
Total	29				

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

Grand Mean 83.400 CV 5.90 115

**Appendix 39: Analysis of variance for percentage contact ground cover at LRS in March of season 1 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	317.40	158.700		
Rotation	9	762.13	84.681	0.42	0.9068
Error	18	3619.27	201.070		
Total	29				

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

Grand Mean 53.800 CV 26.36

**Appendix 40: Analysis of variance for percentage contact ground cover at LRS in March of season 2 (Experiment 1)**

Source DF SS MS F P

Replicate 2 58.067 29.0333

Rotation 9 82.833 9.2037 0.46 0.8836

Error 18 361.267 20.0704

Total 29

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

Grand Mean 46.833 CV 9.57

**Appendix 41: Analysis of variance for percentage contact ground cover at LRS in June of season 1 (Experiment 1)**

Source DF SS MS F P

Replicate 2 5.267 2.6333

Rotation 9 550.133 61.1259 5.56 0.0010

Error 18 198.067 11.0037

Total 29

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

Grand Mean 38.533 CV 8.61

**Appendix 42: Analysis of variance for percentage ground cover at LRS in June of season 2 (Experiment 1)**

Source	DF	SS	MS	F	P
Replicate	2	1722.4	861.217		
Rotation	9	6152.0	683.556	0.99	0.4820

Error	18	12447.2	691.512
Total	29		

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

Grand Mean 51.573 CV 50.99